Airframe related aeroacoustics of transport aircraft

–research into prediction and reduction of sound radiation–

Presentation NASA Ames, 07/10/2013

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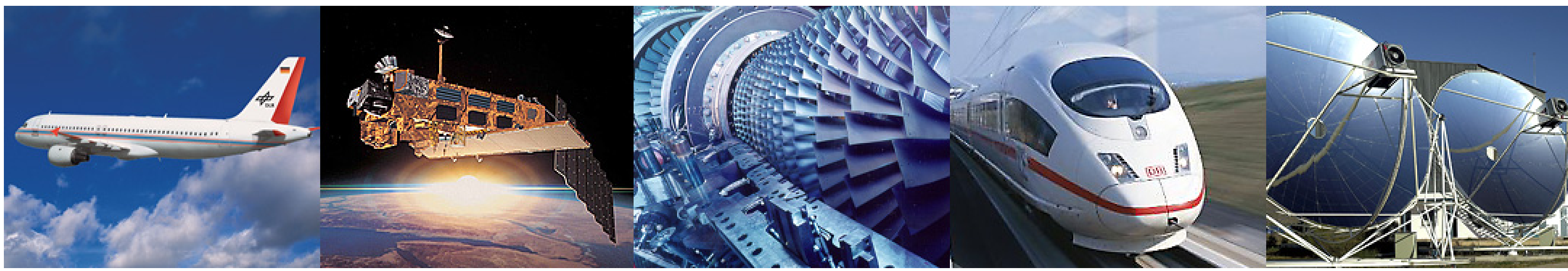
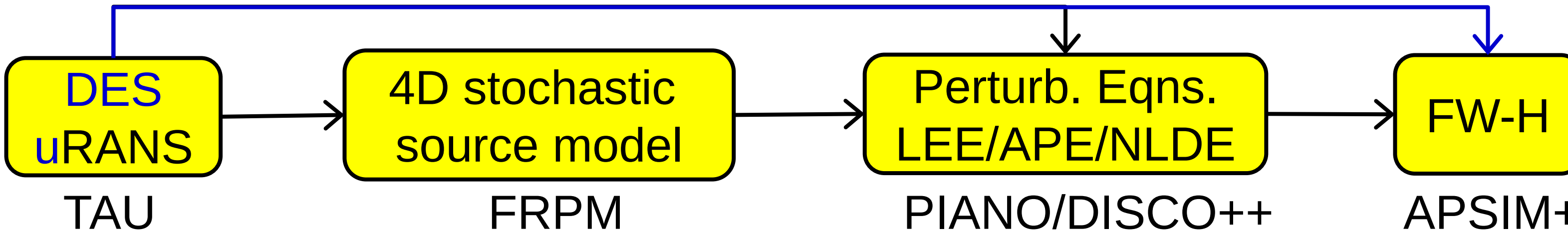


- Research Institution for Aeronautics, Space, Transport, Energy
- Space Agency
- Project Management Agency

Tools

Prediction & Design

- component sound generation & propagation:



- complete a/c acoustic installation: FM-BEM ray tr.
- complete a/c airframe noise estimation: semi-empirical

Testing & Validation

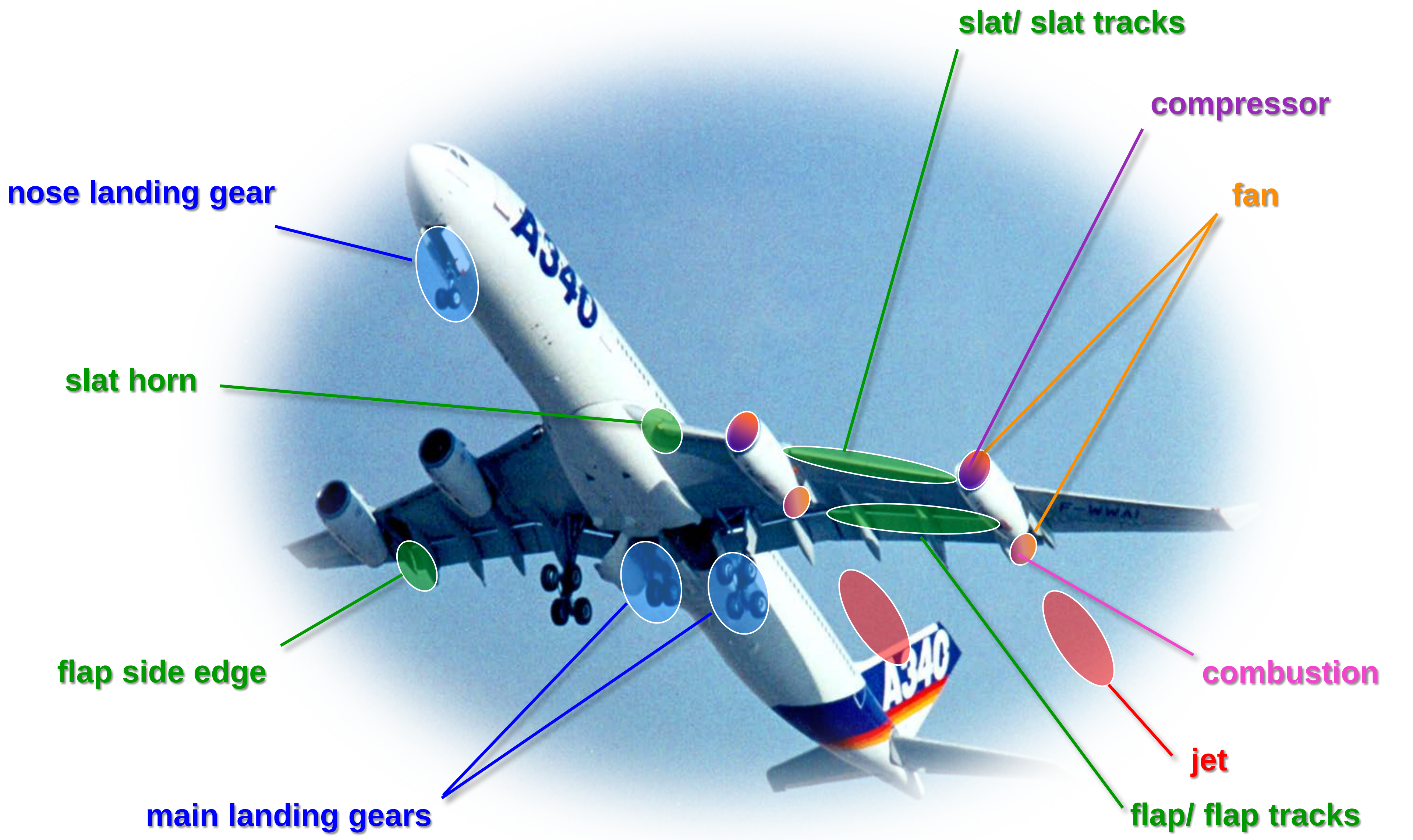
- acoustic wind tunnels (AWB, NWB, LLF, …)
- flyover testing (A320 ATRA, G550 HALO,…)

Outline

- Introduction - definition of topic
- Airframe related aircraft noise
- conclusions
- outlook

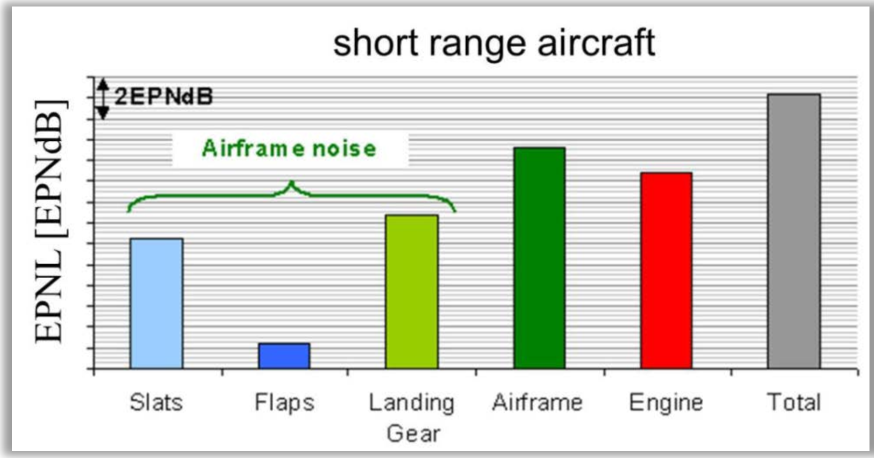
Introduction

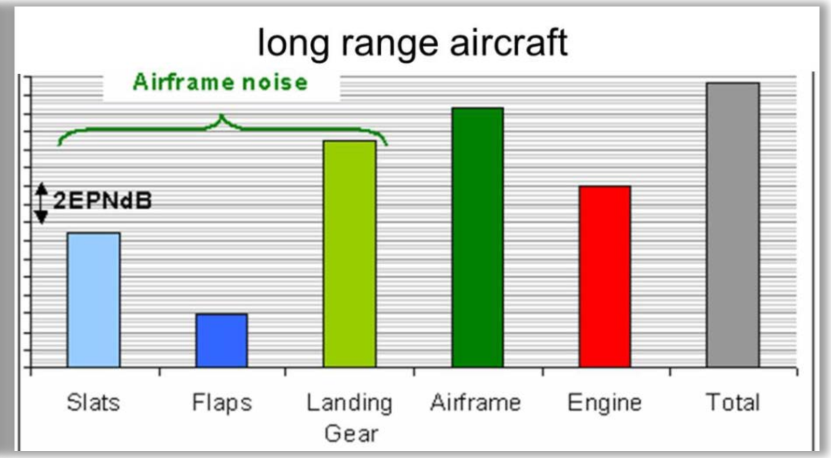
„Classical“ sources of exterior noise at aircraft

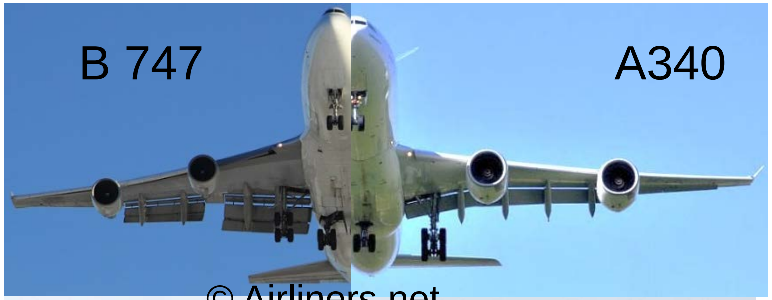


Typical rank ordering of sources at approach

Source: Airbus







Airframe related aircraft noise

1. Airframe (component) noise
   - generation of sound due to (turbulent) flow past airframe components „noise of an aircraft flying at engines off“
2. Source installation effects (exterior + interior noise)
3. Acoustic installation effects (exterior + interior noise)

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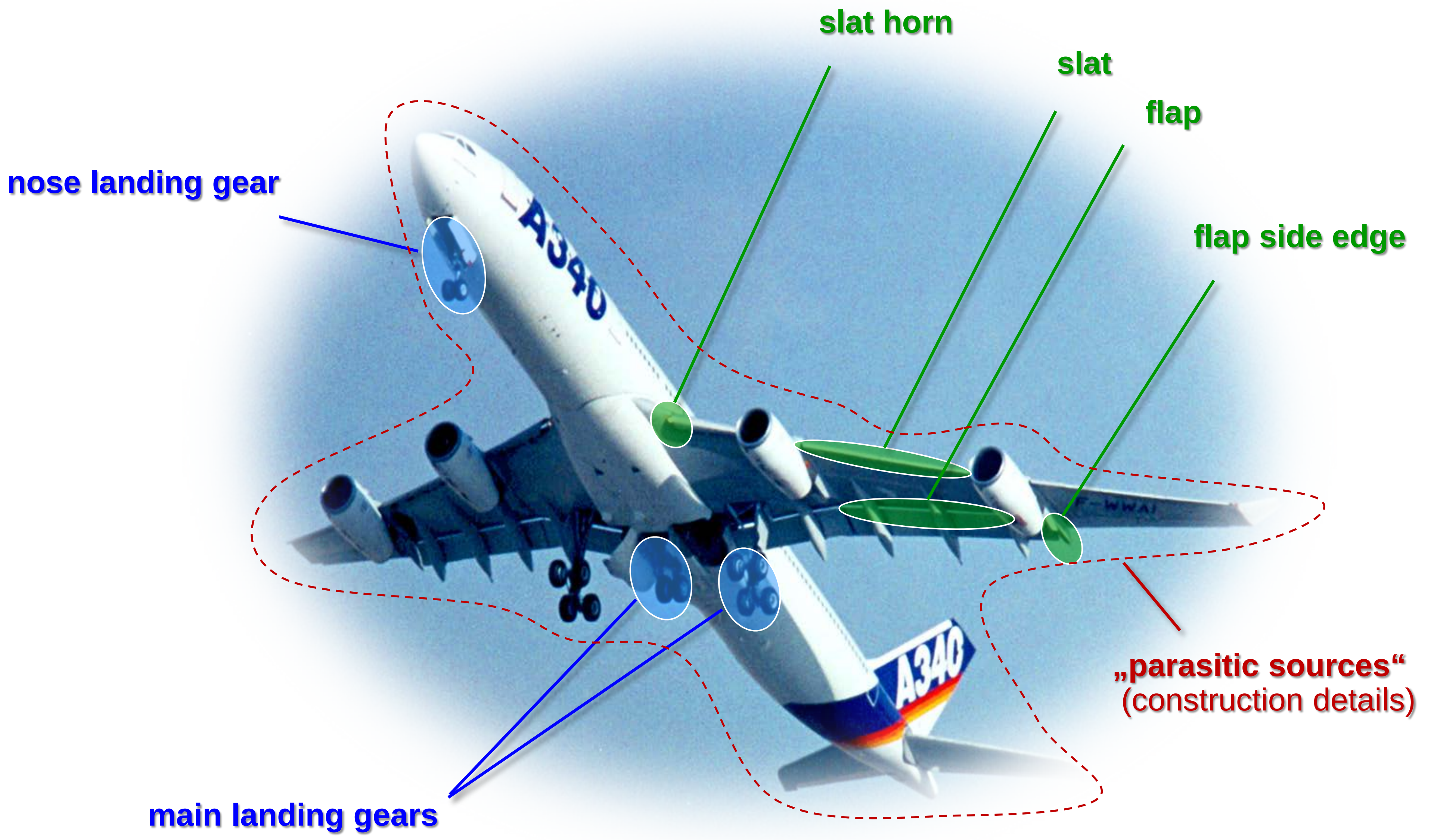
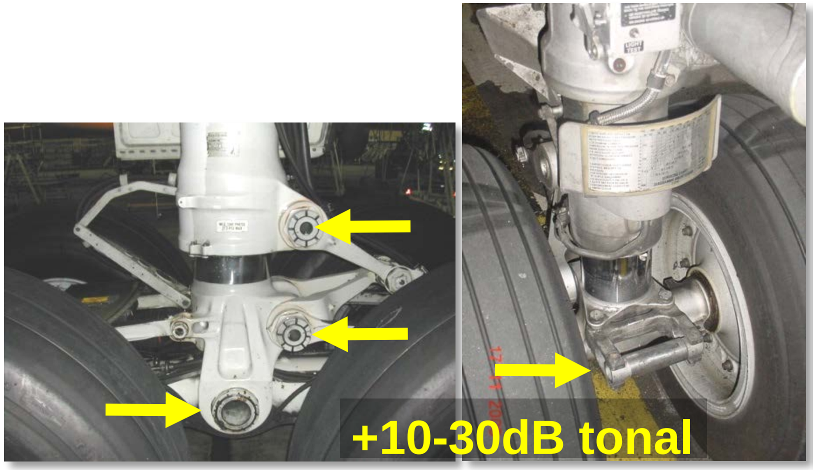
„Classical“ sources of airframe noise at aircraft



Parasitic sources at real a/c airframes

- tone noise from pin-holes in landing gear pins/bolts (hollow for weight reasons)

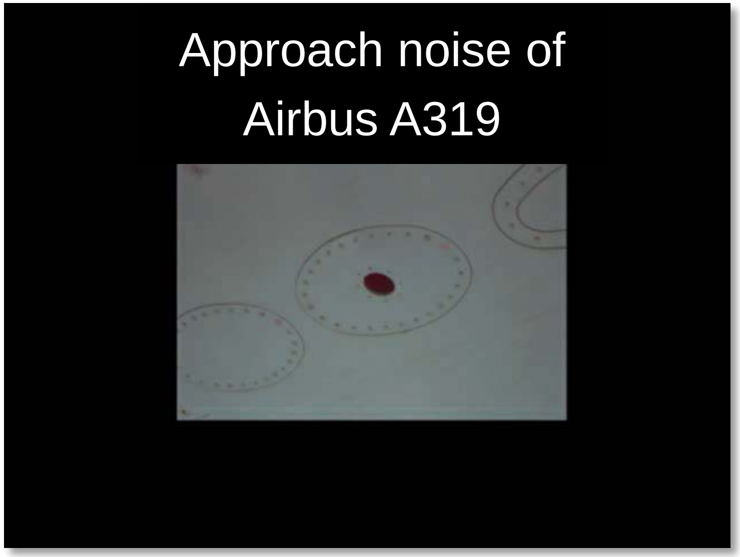


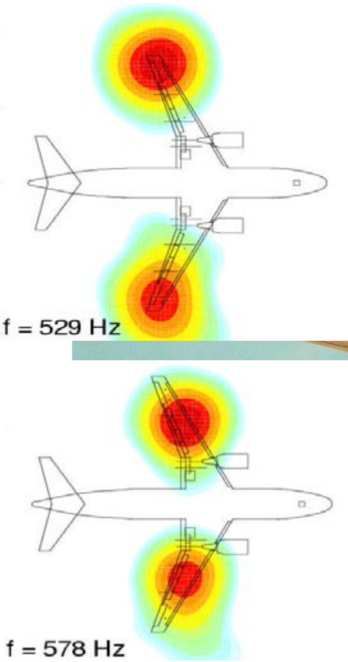
- tone noise from pressure release openings

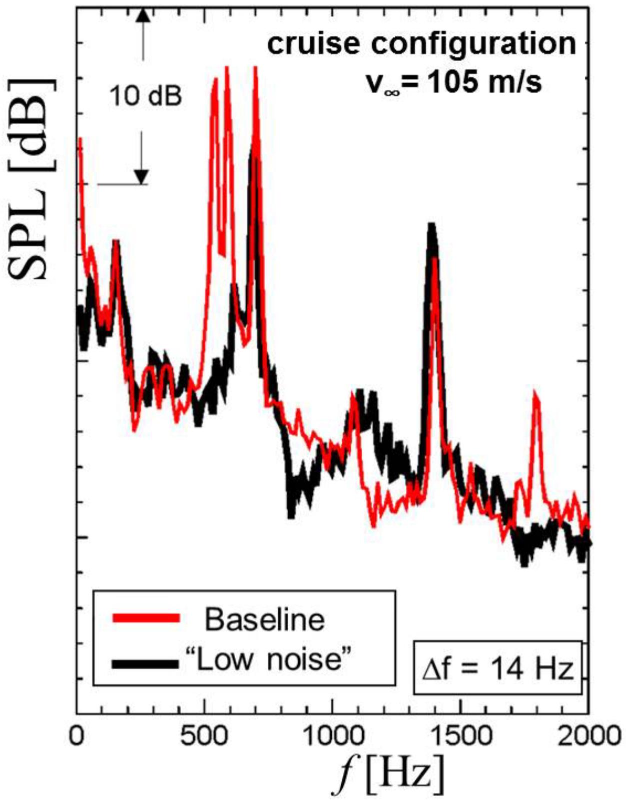
- broadband excess noise from slat/flap tracks

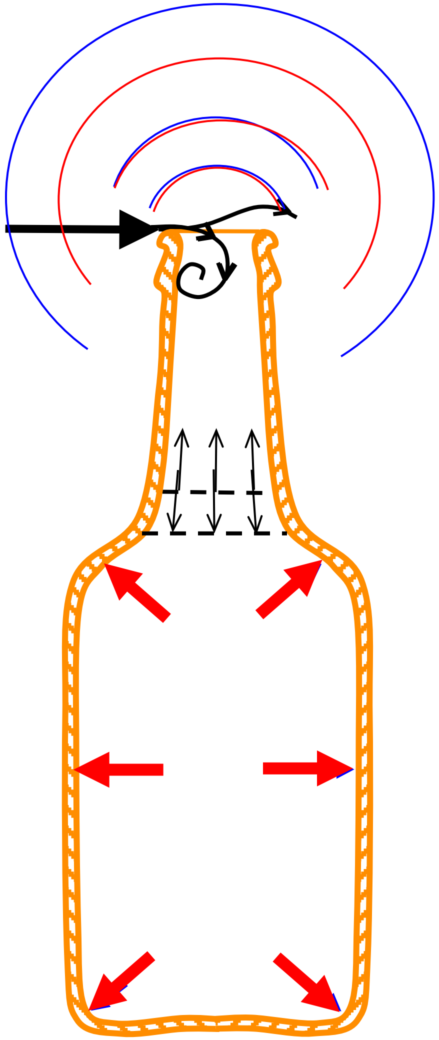
- broadband excess noise from recessed geometries

Parasitic tones at wings







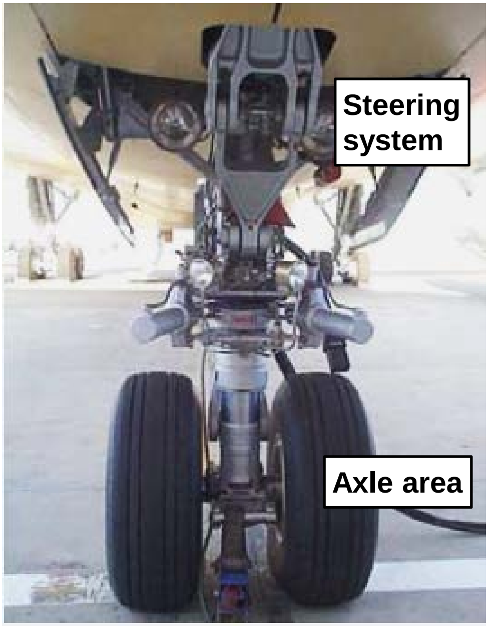


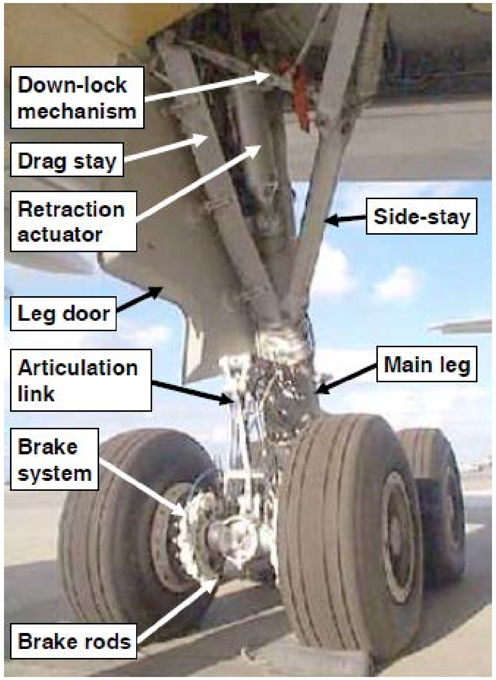
Helmholtz resonator

-M. Pott-Pollenske et al. 2002

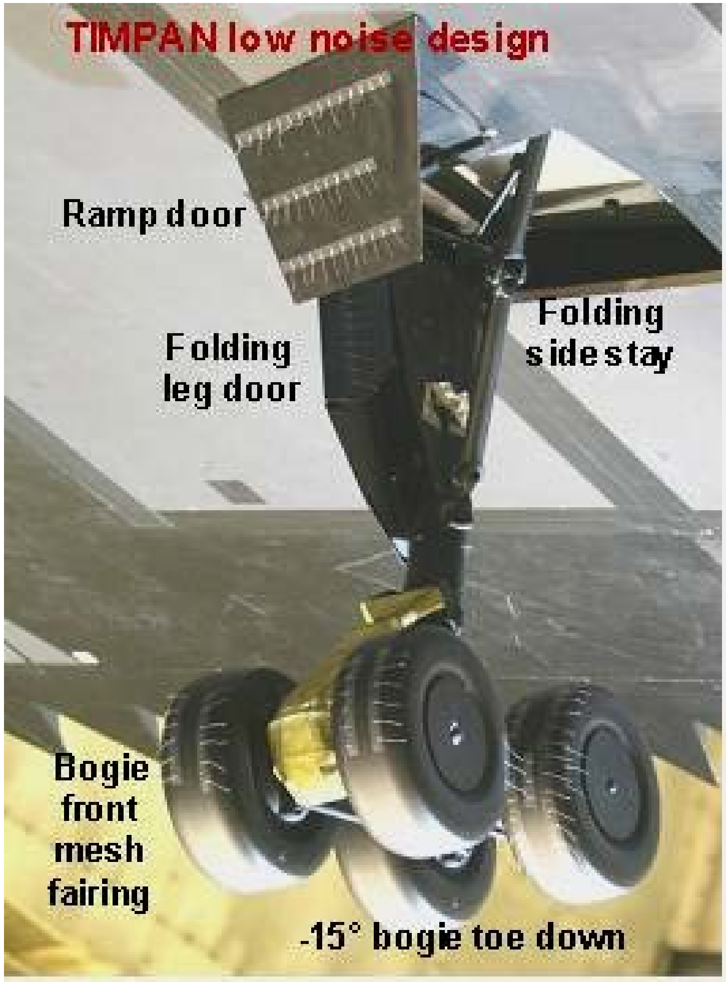
Landing gear noise

- considerable experimental research during past 15 years in EU and USA
- most important source of airframe noise (at certifcation point)
- very broadband in character (slow roll-off of spectrum)
- Size^2 scaling of intensity for similar geometry (in all details!)
- Speed^6 scaling of intensity (compact source components)
- No pronounced directivity due to complex cluster of compact sources
- flyable noise reduction measures and new designs successfully developed for NLGs and MLGs

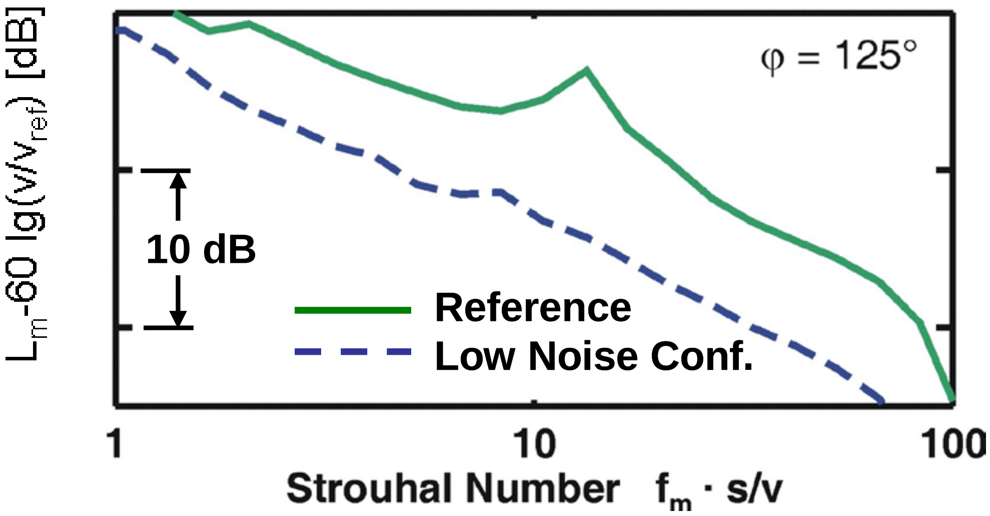




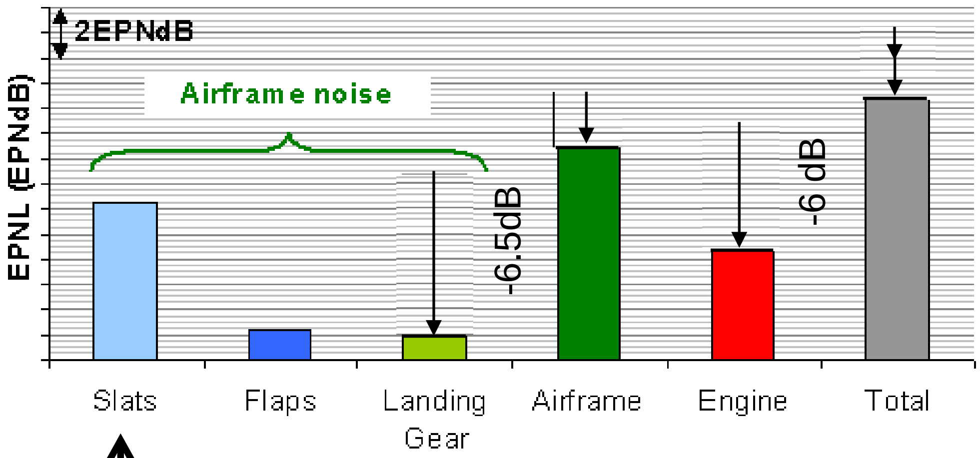
Low noise main landing gear

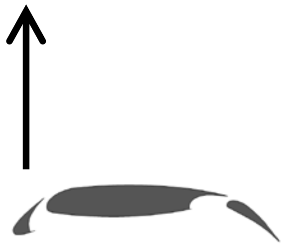


Optimal combination of modifications yields up to 8 dB(A) source noise reduction for flyable solution



Significance of high lift devices for airframe noise

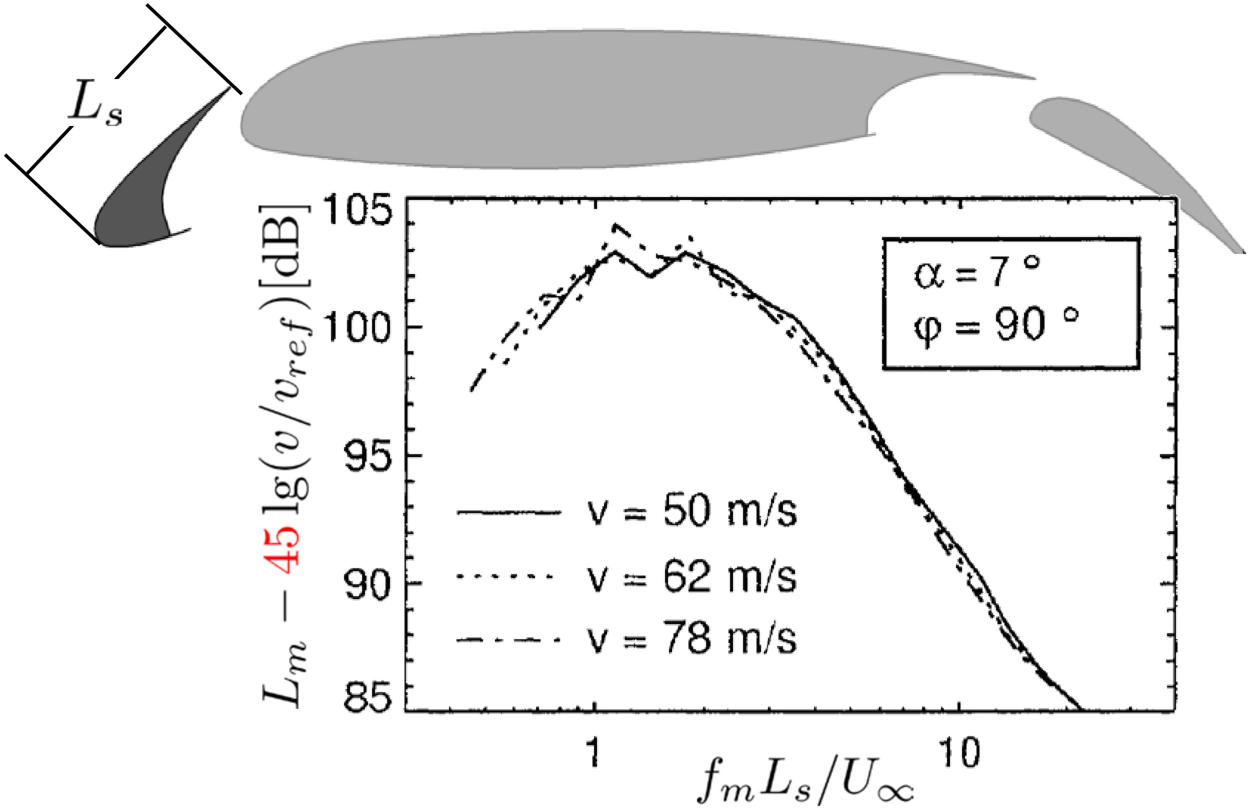




→ Noise reduction at landing gear of limited effect for a/c if HLD unaltered

- But: much more difficult to improve, since aerodynamically highly optimized component

Characteristics of slat noise



- significance and main parametric dependencies found by Dobrzynski, 1997/98, hypothesis: trailing edge mechanism
- most physics-based description so far by Guo‘s model 2010 (not predictive)
- origin of low frequency spectral characteristics unknown

What mechanism generates low frequency broadband signals in slat flows?

- fluctuating pressure from Poisson equation (incompressible flow near wall)

$$\Delta p' = -\rho_\infty \boldsymbol{\nabla}\cdot\boldsymbol{\nabla}\cdot(\boldsymbol{v}\boldsymbol{v})' = -\rho_\infty({}^t\boldsymbol{\nabla}\boldsymbol{v}\boldsymbol{:}\boldsymbol{\nabla}\boldsymbol{v})'$$

- decomposition in mean + fluctuation $\boldsymbol{v} = \boldsymbol{v}^0 + \boldsymbol{v}'$

$$\Rightarrow \Delta p' \simeq -2\rho_\infty({}^t\boldsymbol{\nabla}\boldsymbol{v}^0\boldsymbol{:}\boldsymbol{\nabla}\boldsymbol{v}')$$

- order of magnitude estimation like

$$p'/l_\omega^2 \sim 2\rho_\infty|\boldsymbol{\nabla}\boldsymbol{v}^0|\frac{\sqrt{k}}{l_\omega} \qquad \text{with} \qquad |\boldsymbol{\nabla}\boldsymbol{v}^0| = \sqrt{\boldsymbol{\nabla}\boldsymbol{v}^0\boldsymbol{:}\boldsymbol{\nabla}\boldsymbol{v}^0}$$

What mechanism generates low frequency broadband signals in slat flows?

- time scale from LEE pressure equation (compressive part neglected)

$$\frac{\partial p'}{\partial t} \simeq -\boldsymbol{v}^0 \cdot \boldsymbol{\nabla} p' - \boldsymbol{v}' \cdot \boldsymbol{\nabla} p^0$$

$$p'/l_\omega^2 \sim 2\rho_\infty |\boldsymbol{\nabla}\boldsymbol{v}^0| \frac{\sqrt{k}}{l_\omega}$$

$$f_v := \frac{1}{p'}\frac{\partial p'}{\partial t} \sim \frac{|\boldsymbol{v}^0|}{l_\omega} \sim \frac{v_\infty}{l_\omega}$$

convective frequency

$$f_p := \frac{1}{p'}\frac{\partial p'}{\partial t} \sim \frac{\sqrt{k}|\boldsymbol{\nabla} p^0|}{2\rho_\infty l_\omega |\boldsymbol{\nabla}\boldsymbol{v}^0|\sqrt{k}} = \frac{|\boldsymbol{\nabla} p^0|}{2\rho_\infty l_\omega |\boldsymbol{\nabla}\boldsymbol{v}^0|}$$

non-convective frequency

$$|\boldsymbol{\nabla} p^0| \sim \rho_\infty v_\infty^2 / L_s$$

$$|\boldsymbol{\nabla}\boldsymbol{v}^0| \sim v_\infty / l_\omega$$

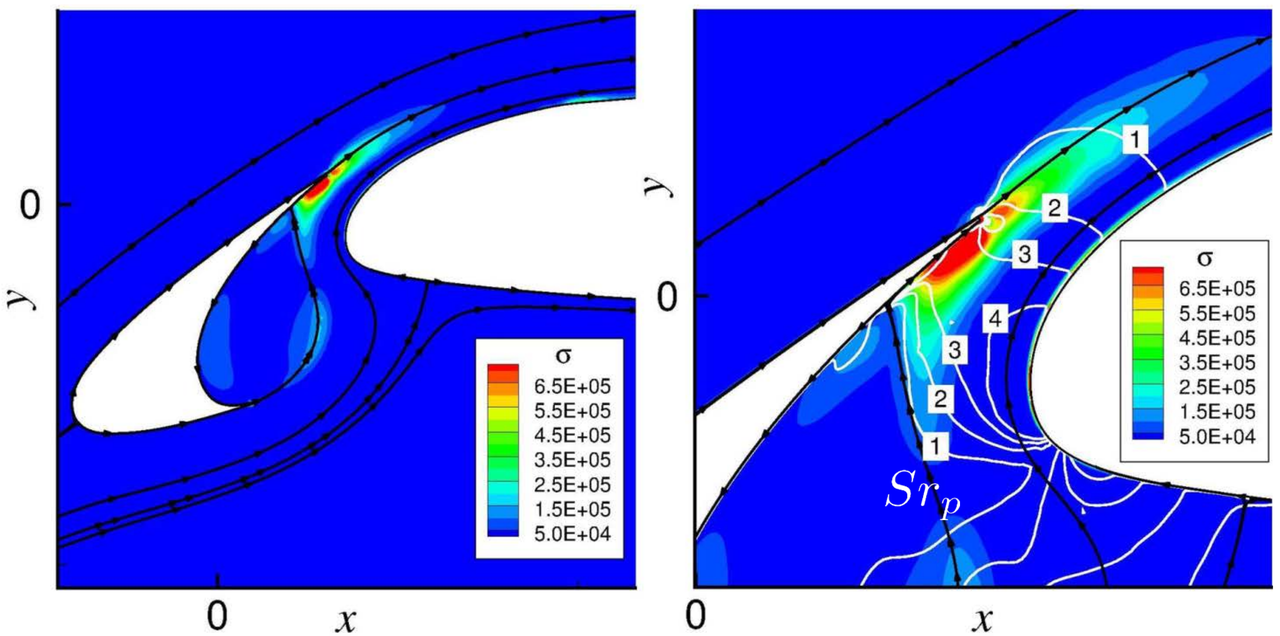
$$\Rightarrow f_p = \frac{v_\infty}{2L_s}$$

$$\Rightarrow f_c L_s / v_\infty =: \boxed{Sr_v = O(L_s/l_\omega)}$$

$$\Rightarrow f_p L_s / v_\infty =: \boxed{Sr_p = O(1)}$$

What mechanism generates low frequency broadband signals Sr~1 in slat flows?

- repeat dimensional analysis with locally available data from RANS:



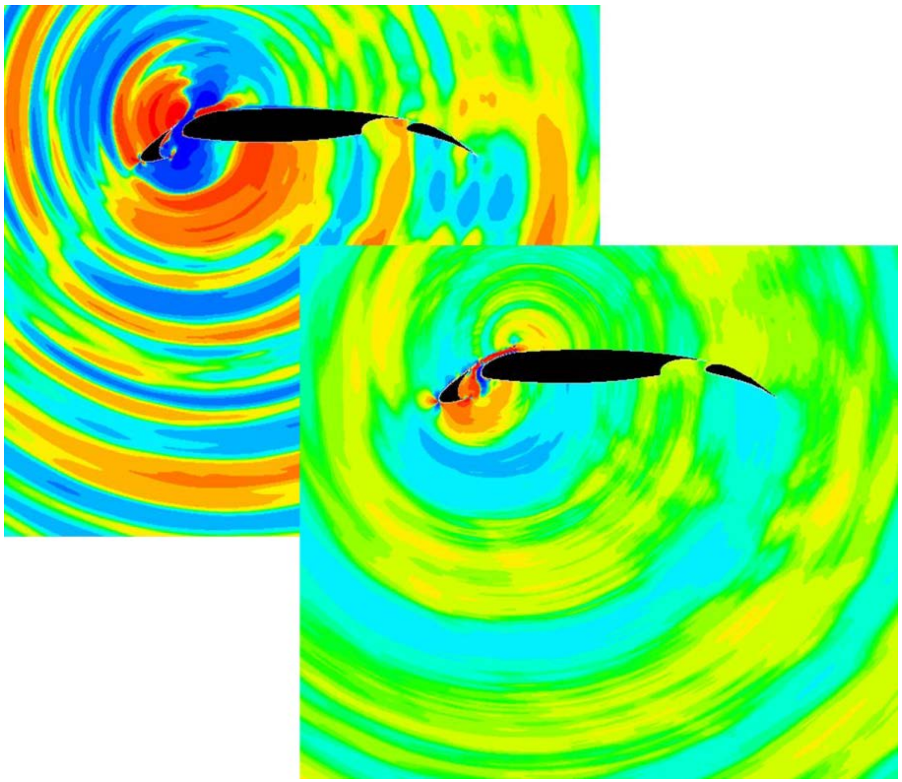
$$\sigma := \sqrt{k}|\nabla p^0| \sim \frac{\partial p'}{\partial t}$$

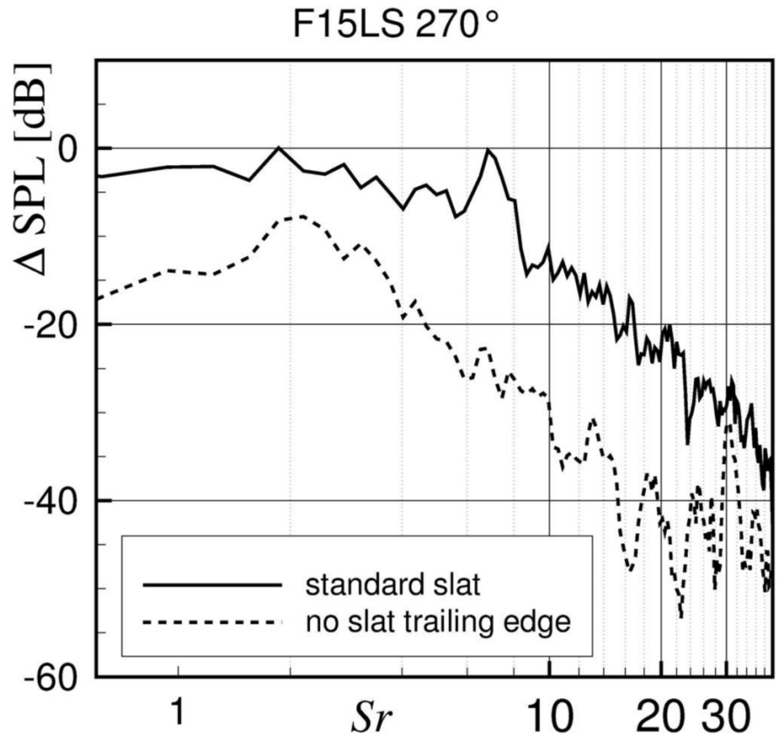
„source“ due to Ribner or Seo, Moon (LPCE)

$\Rightarrow$ Source near trailing edge which is no trailing edge source (need no edge)

What mechanism generates low frequency broadband signals Sr~1 in slat flows?

- Do CAA simulation with/without slat trailing edge
  („without“ = slat extended by infinitely thin surface along t.e. streamline)

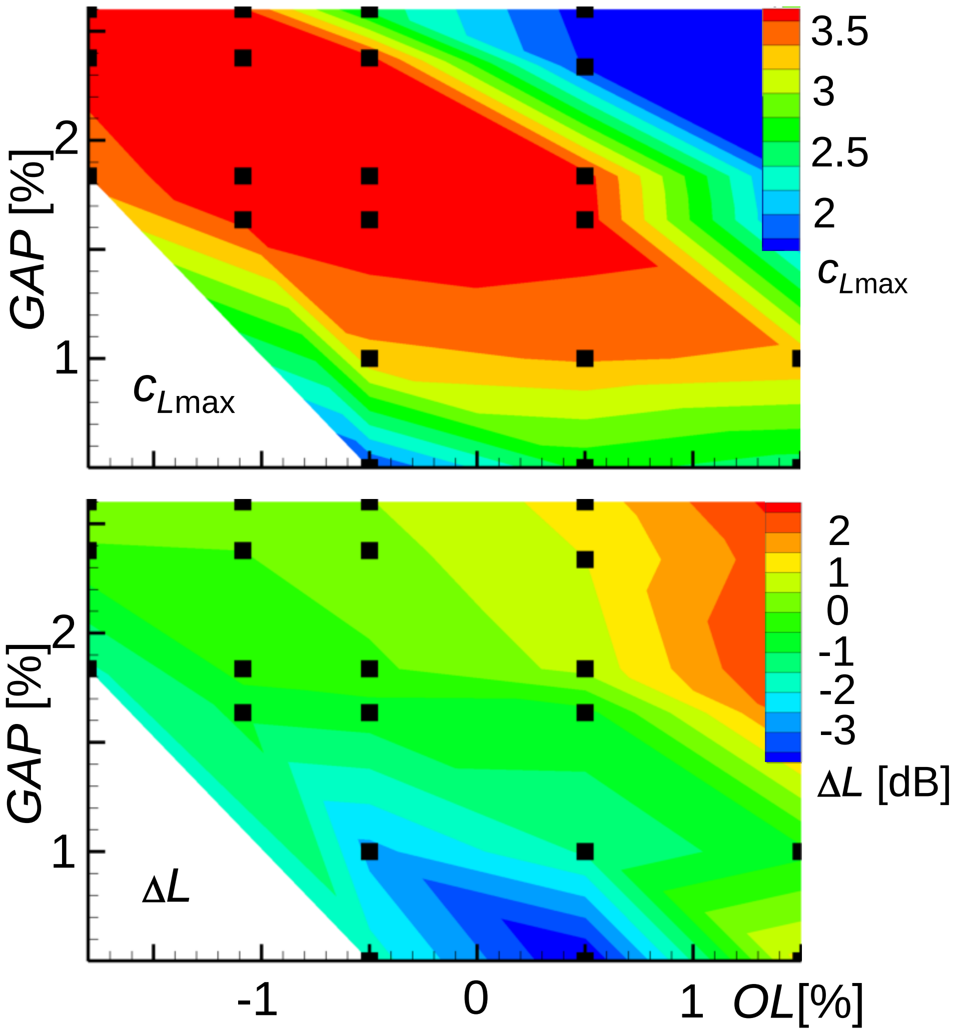


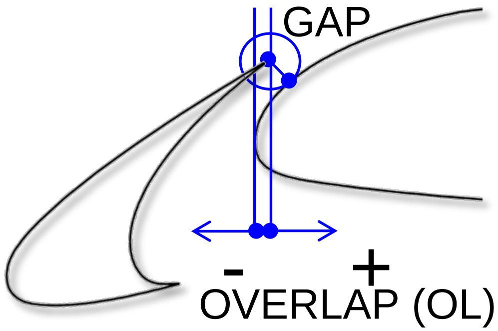


⇒ two sources at work, one due to acceleration, one classical edge noise source

Simulation based aeroacoustic Design

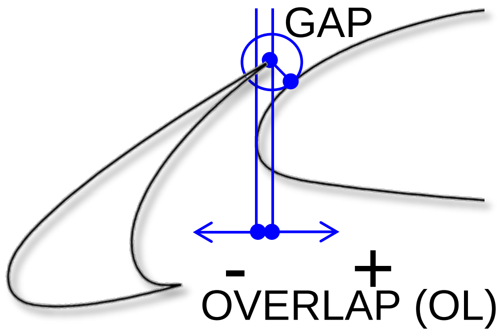
Optimum slat settings





flow: TAU
sound: PIANO

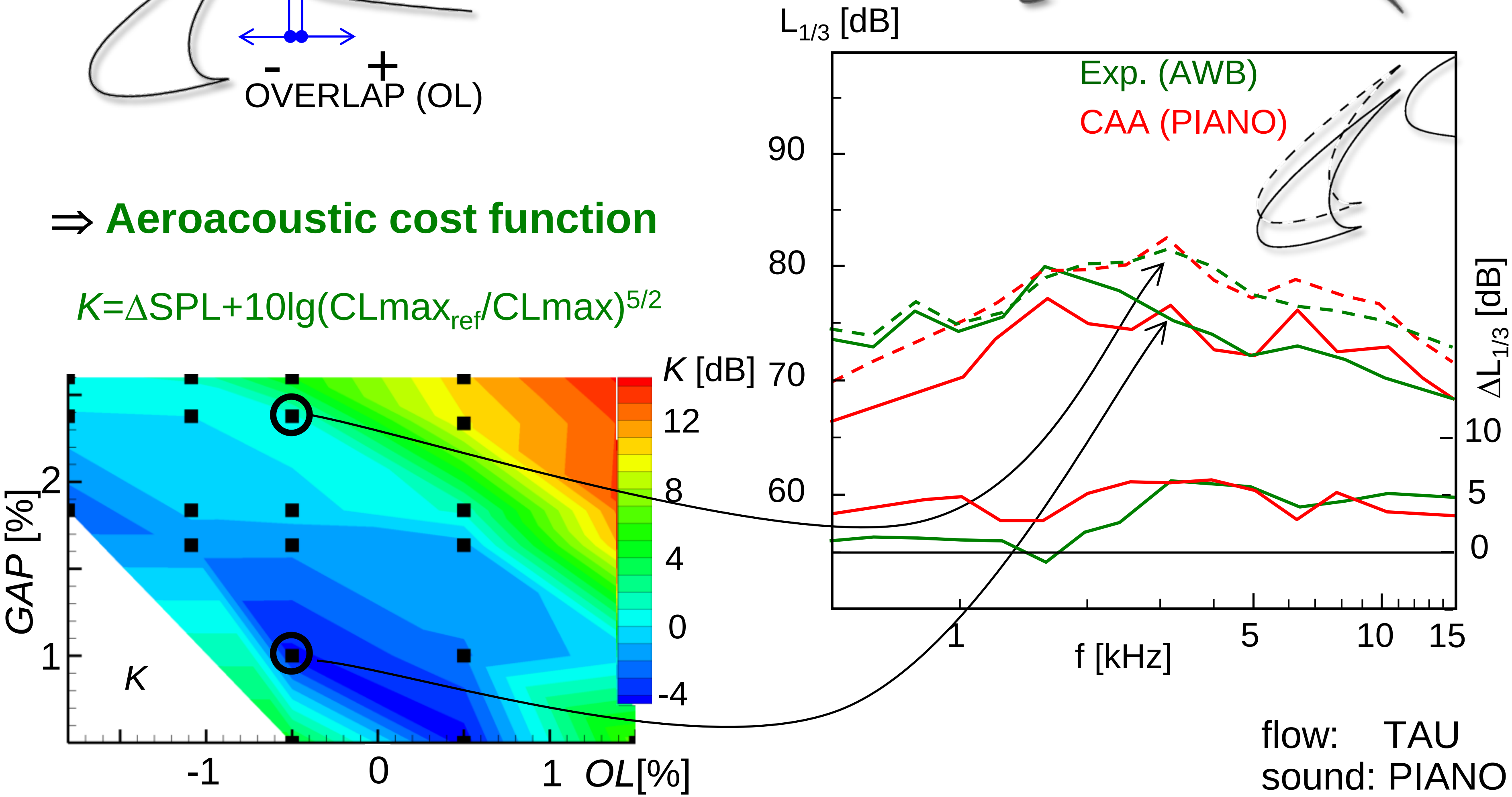
Simulation based aeroacoustic Design



Optimum slat settings

⇒ **Aeroacoustic cost function**

$K = \Delta SPL + 10 \lg(CLmax_{ref}/CLmax)^{5/2}$



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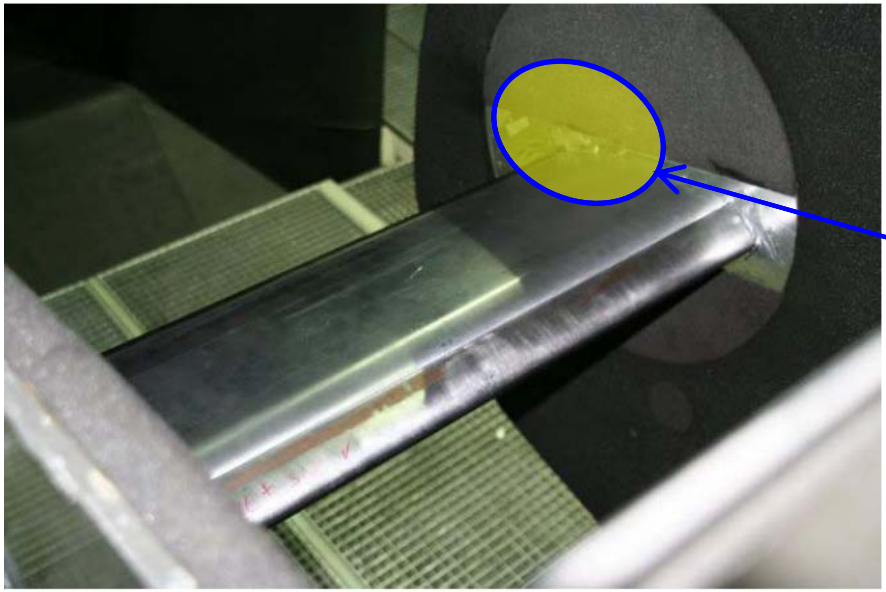
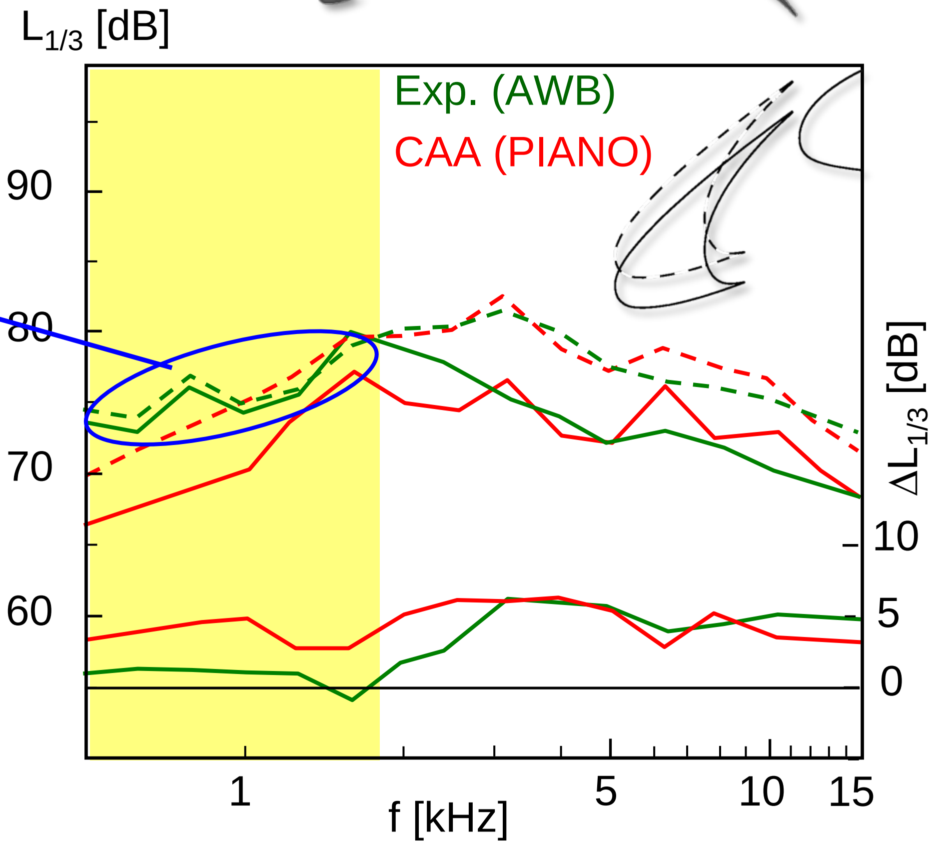
Simulation based aeroacoustic Design

Optimum slat settings



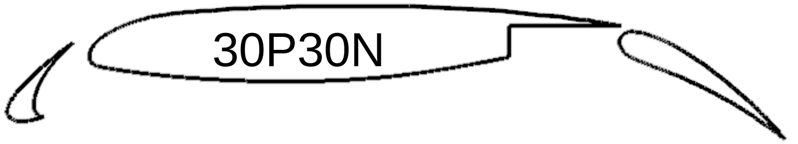


Background noise issue at frequencies below 1.5kHz (spurious noise from model attachment)

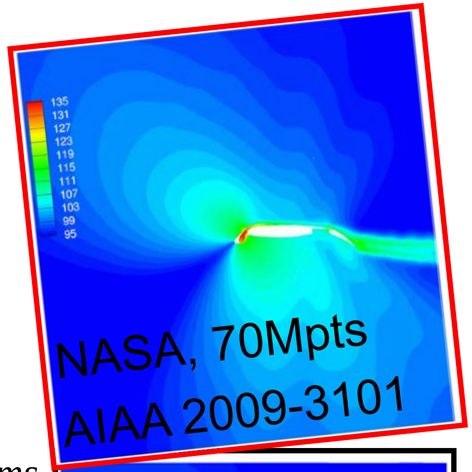
flow: TAU
sound: PIANO

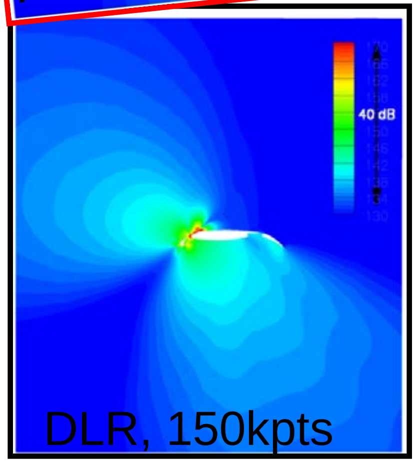
Slat noise of high lift airfoil 30P30N

Comparison of stochastic approach (PIANO) with other groups



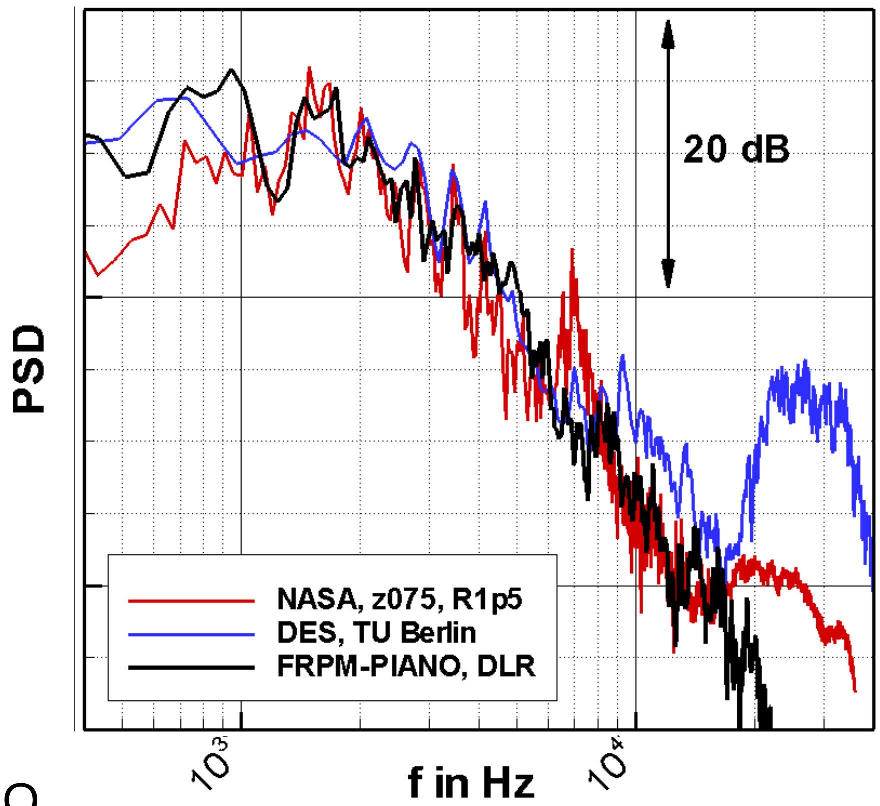
p_{rms}





flow: TAU
sound: PIANO

290° w.r.t. flow



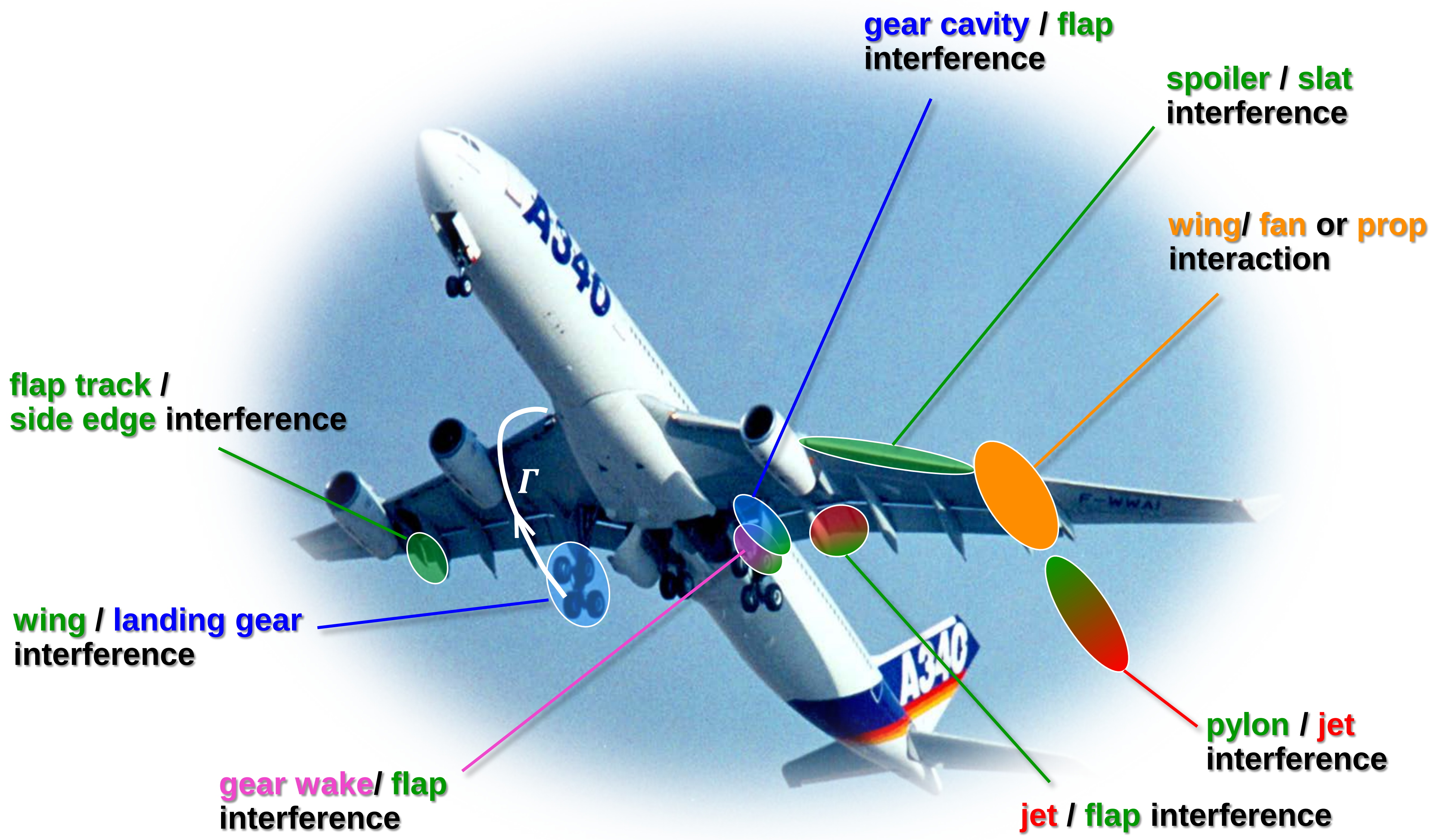
Airframe related aircraft noise

1. Airframe (component) noise
   - generation of sound due to (turbulent) flow past airframe components „noise of an aircraft flying at engines off“

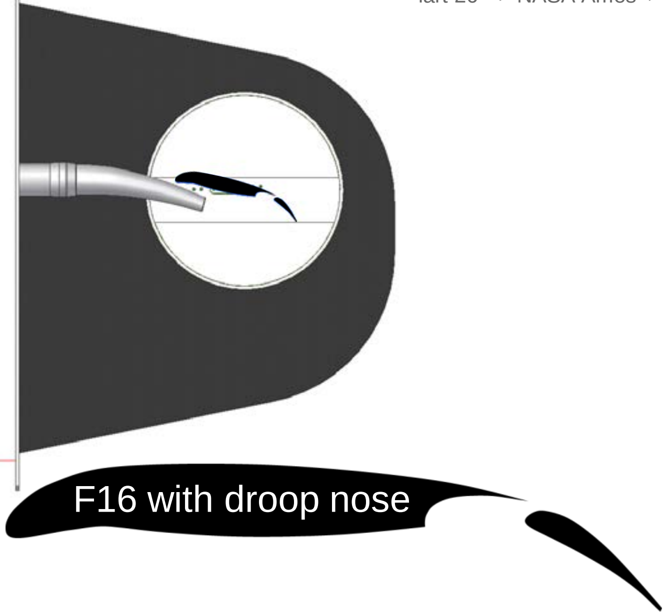
2. Source installation effects (exterior + interior noise)
   - change/occurence of aerodynamic sound generation at an aircraft component due to its attachment to the aircraft
   - typically accompanied by change in/occurence of acoustic power

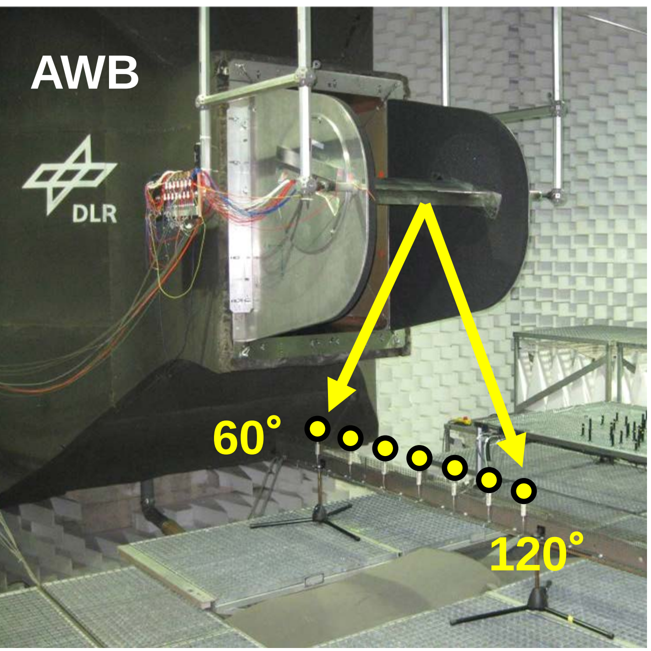
3. Acoustic installation effects (exterior + interior noise)

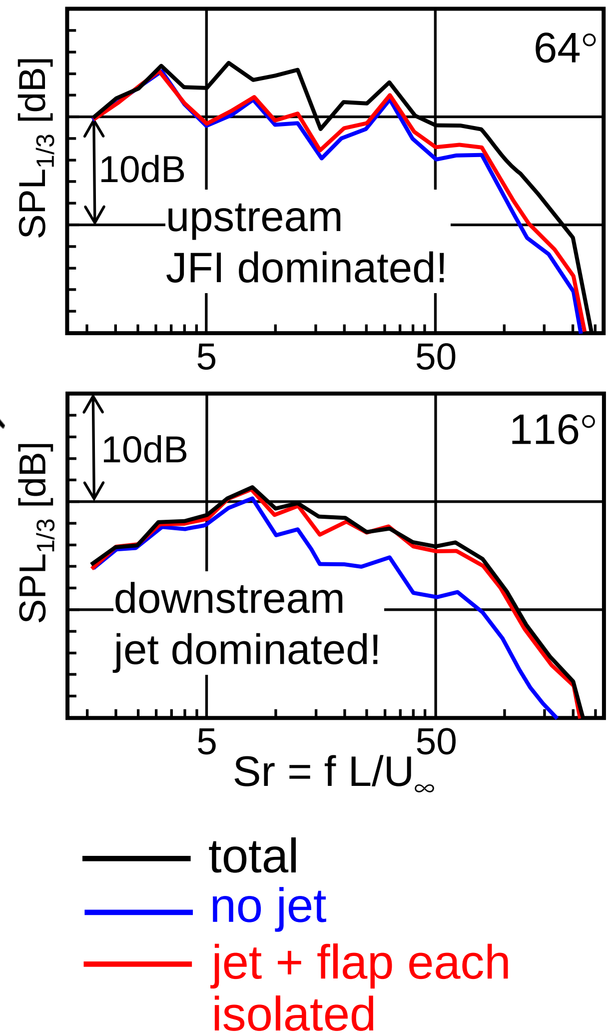
„Installation“ sources of exterior noise at aircraft



Jet flap interference (JFI)

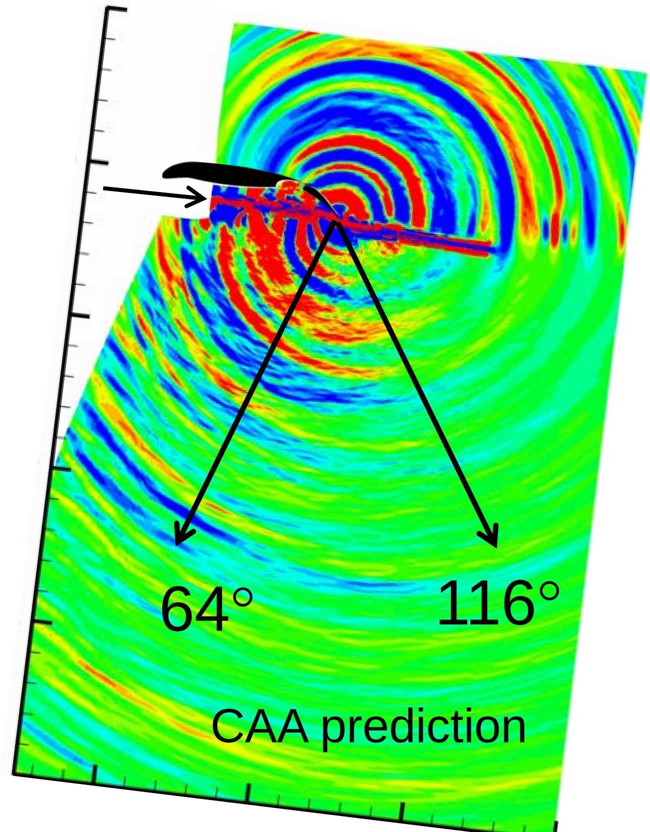






Flight speed U_∞= 60 m/s

Jet speed U_{jet} = 185 m/s (cold single stream jet)



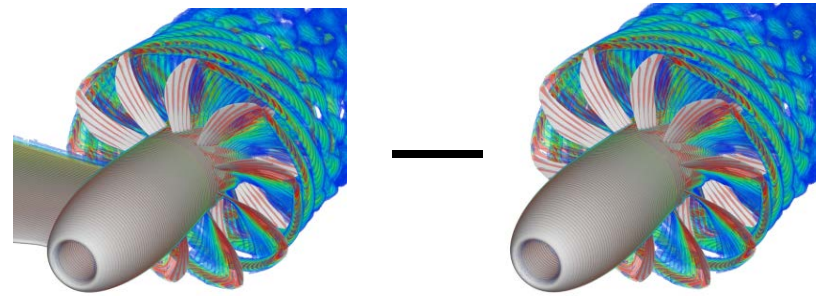
RANS+RPM+APE

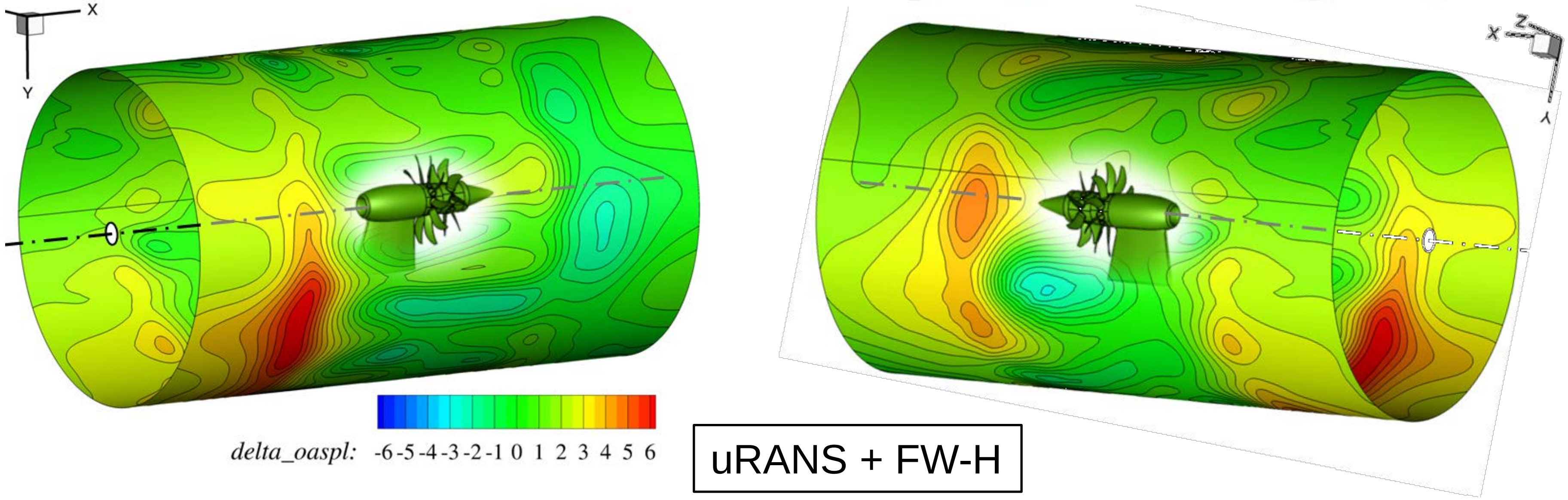
Pott-Pollenske, Dierke, Lufo HIT 2011

Source installation effects of pylon on OR sound generation

Flight Mach No. M=0.2, take-off

Difference in OASPL 10D from rotor axis





- 6.5dB increase upstream on front rotor downstroke side of pylon
- 4.5 dB increase downstream on rear rotor downstroke side of pylon

⇒ Importance of sense of rotation for installation at aircraft

R. Akkermans, A. Stürmer, Delfs DLR 2012

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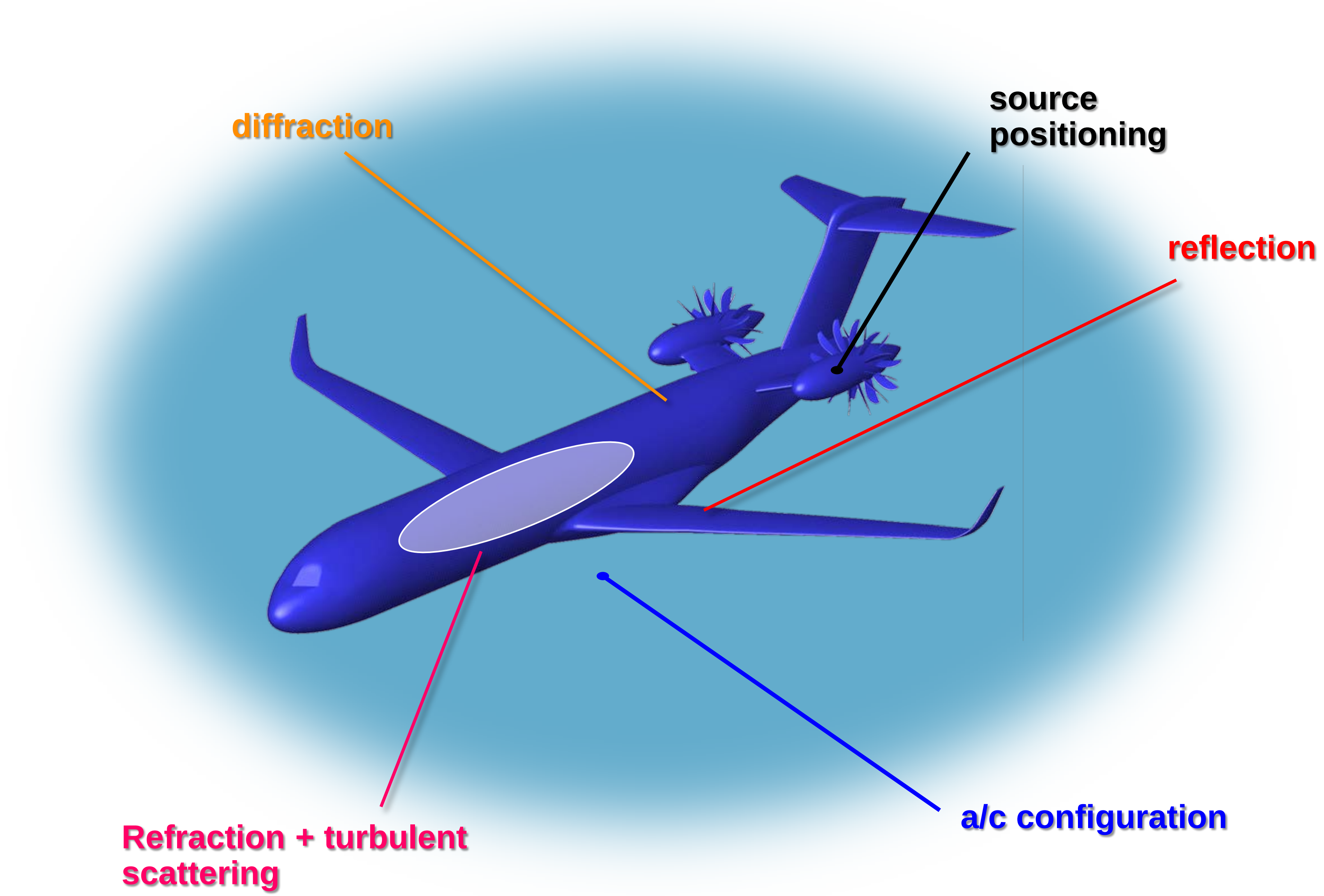
   - generation of sound due to (turbulent) flow past airframe components „noise of an aircraft flying at engines off"

2. Source installation effects (exterior + interior noise)
   - change/occurence of aerodynamic sound generation at an aircraft component due to its attachment to the aircraft
   - typically accompanied by change in/occurence of acoustic power

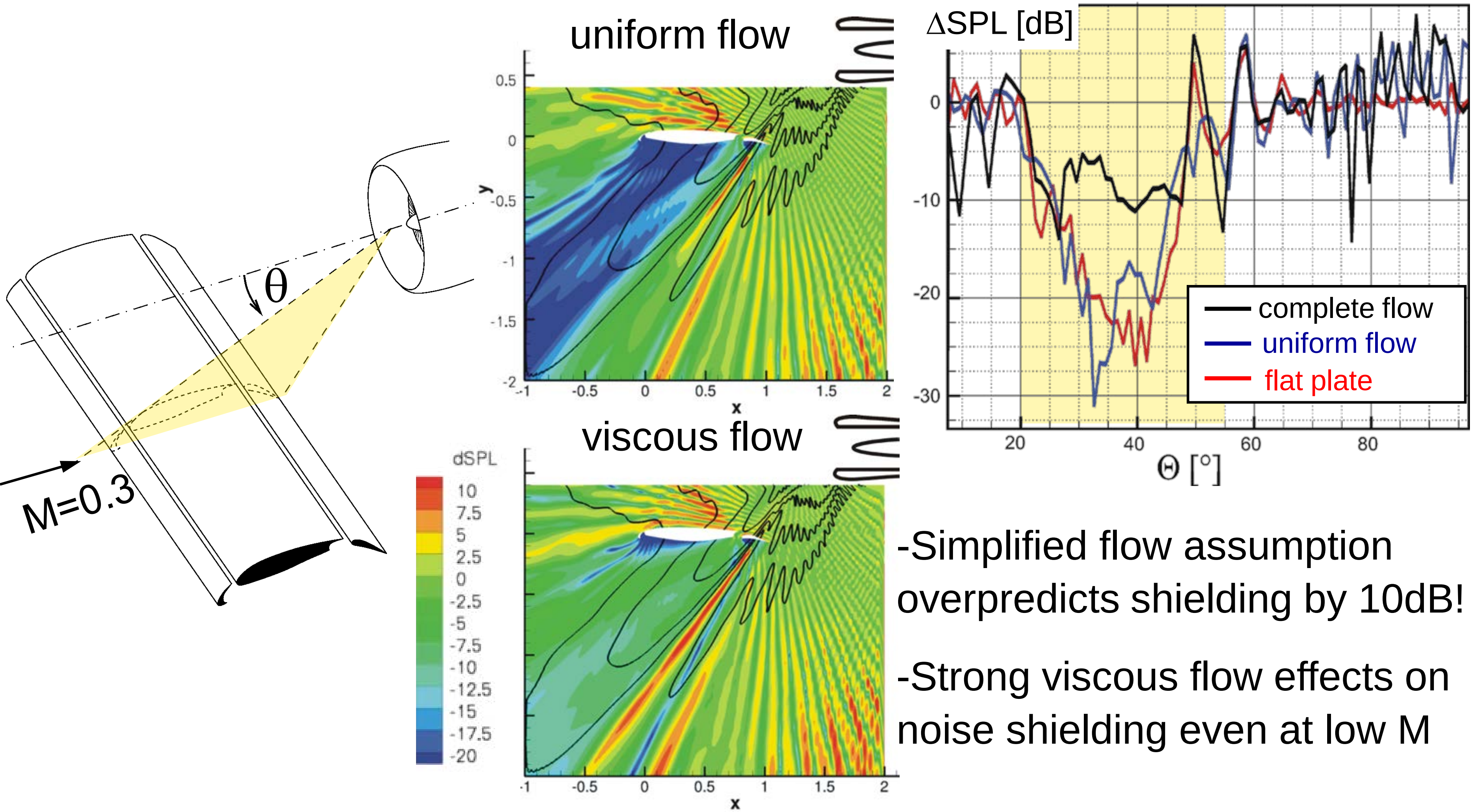
3. Acoustic installation effects (exterior + interior noise)
   - change in the sound radiation of an aircraft component due to influence of the a/c geometry
   - typically not accompanied by change in acoustic power

Acoustic installation phenomena of exterior/interior noise at aircraft



DLR

Unexpected installation effect on fan tones at High Lift Wing

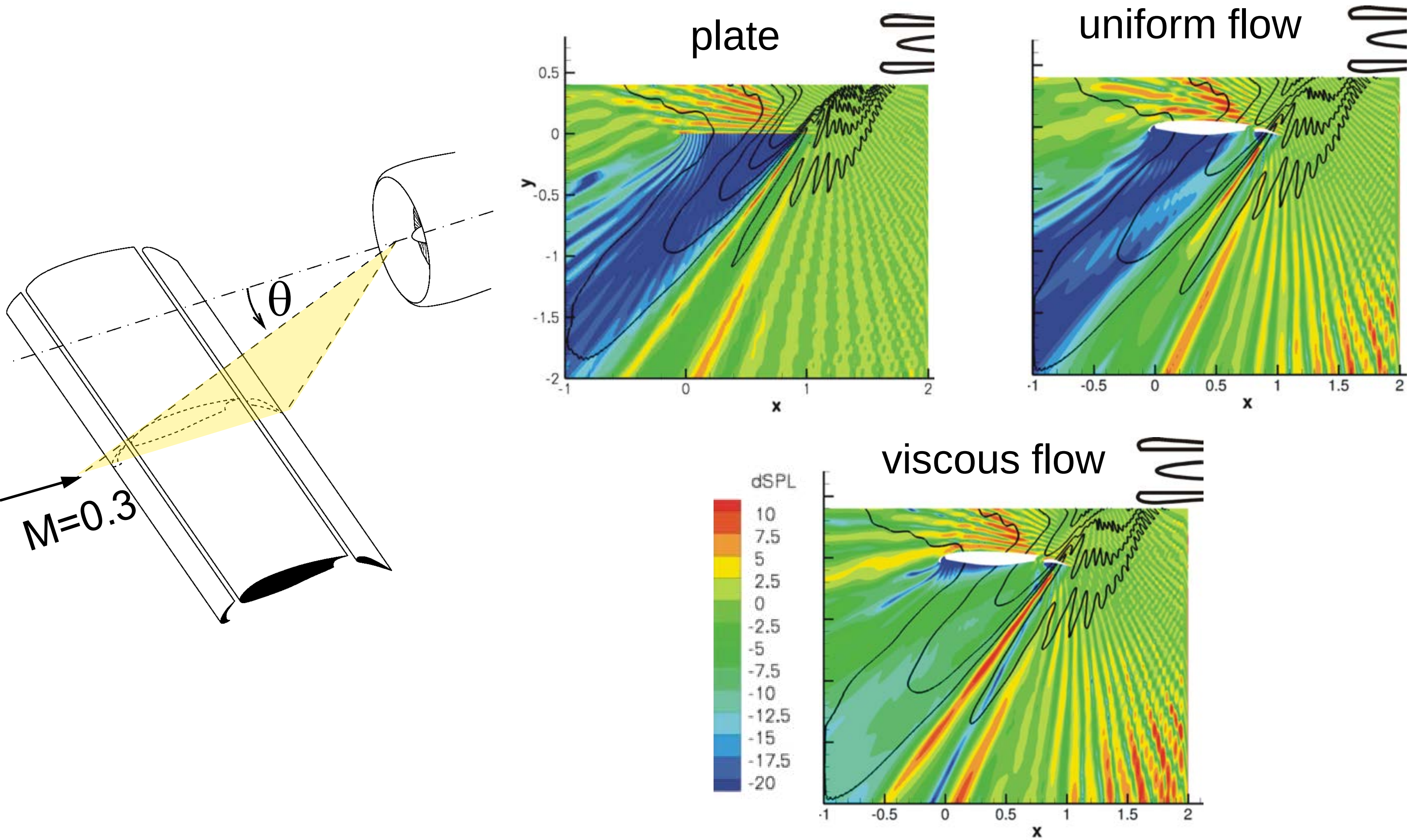


-Simplified flow assumption overpredicts shielding by 10dB!

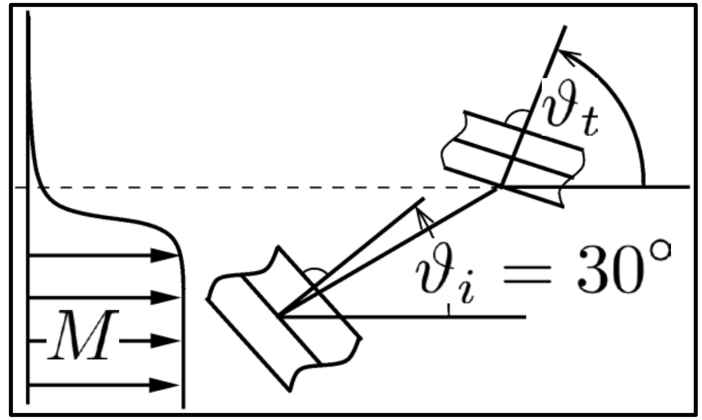
-Strong viscous flow effects on noise shielding even at low M

J. Dierke et al., AIAA 2010-3917

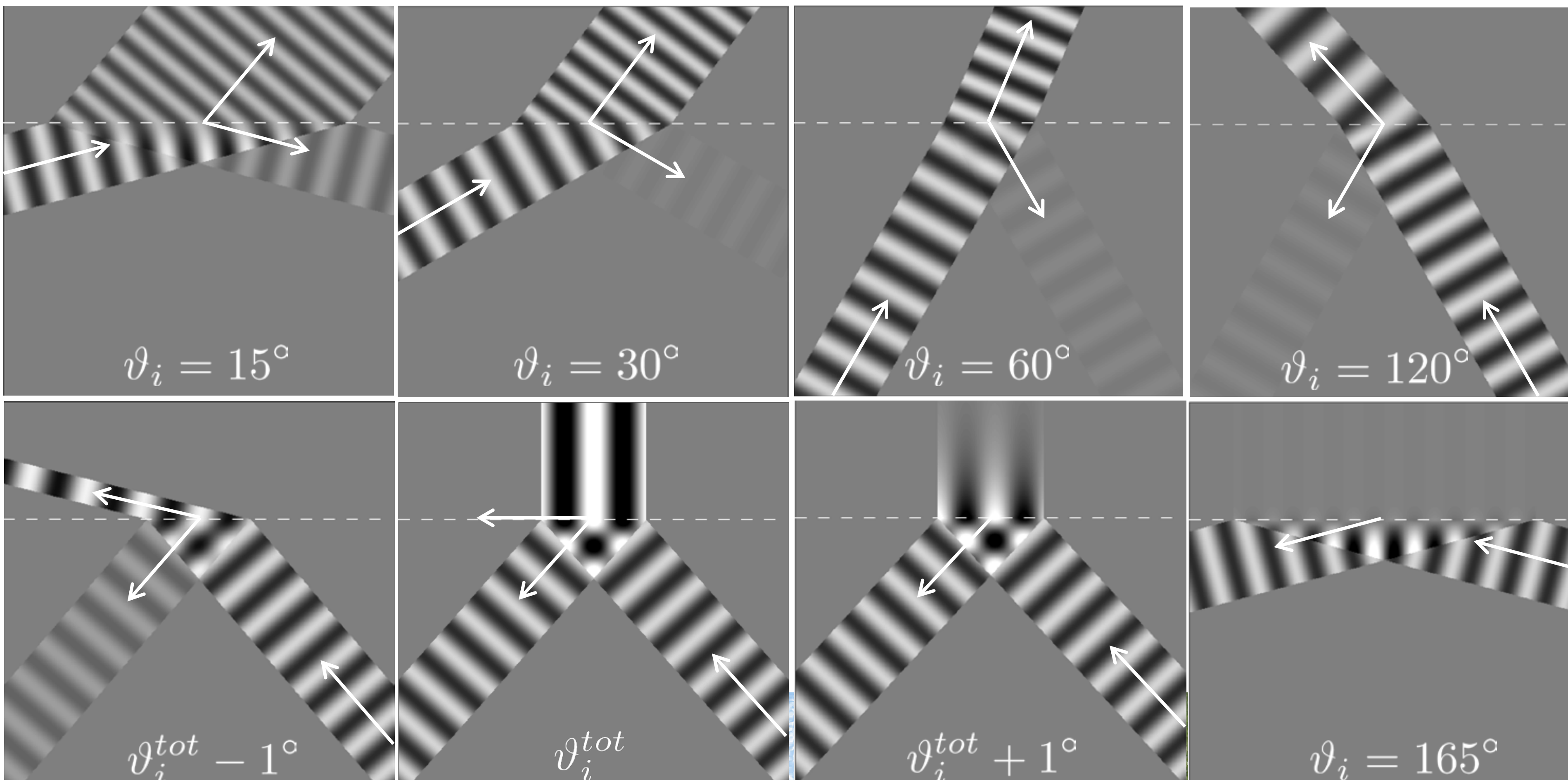
Unexpected installation effect on fan tones at High Lift Wing



Refraction



$M_{-\infty} = 0.5$



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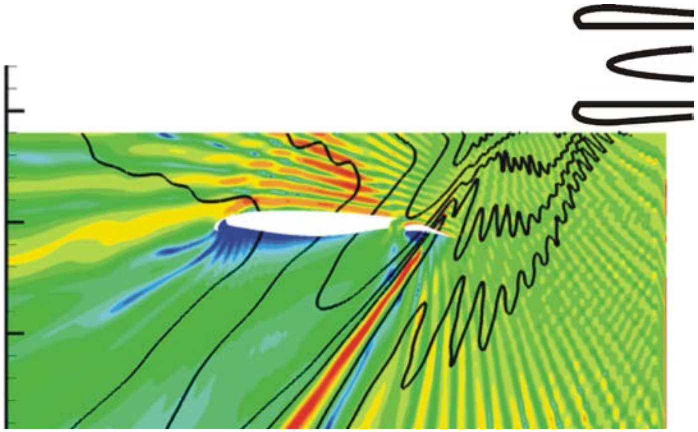

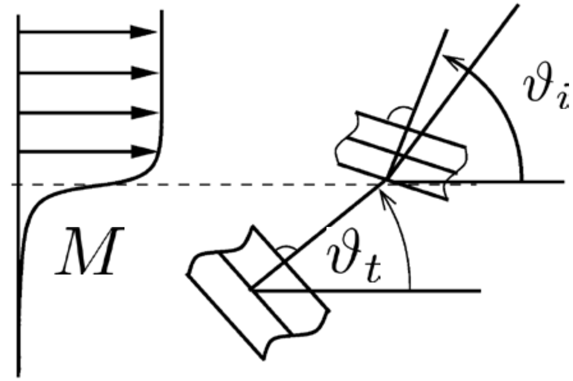

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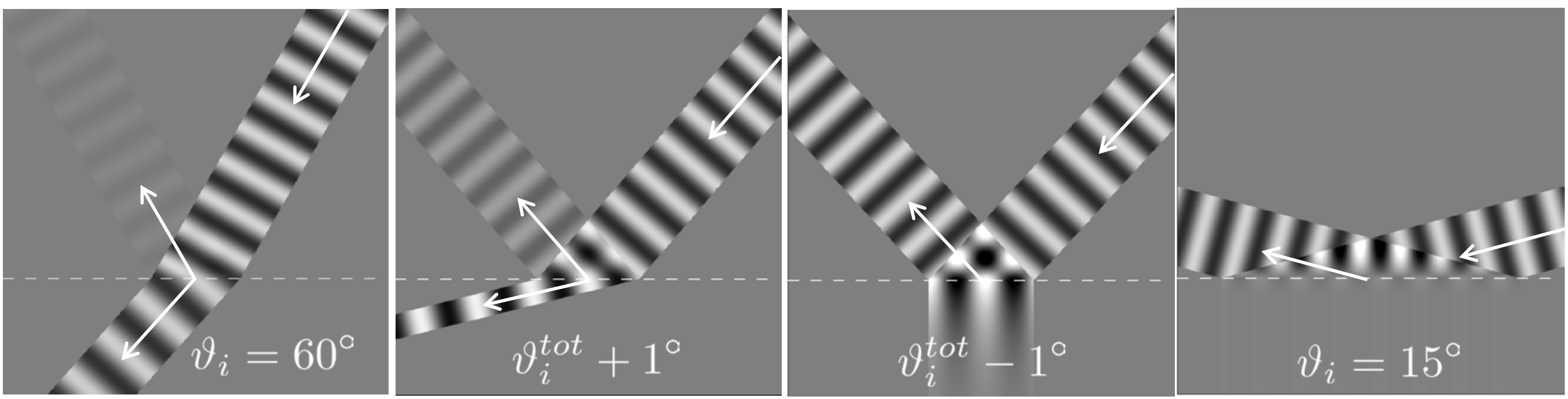

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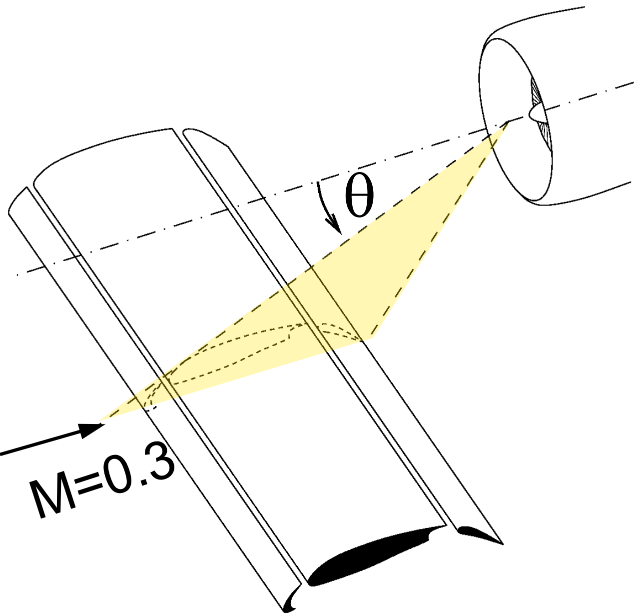
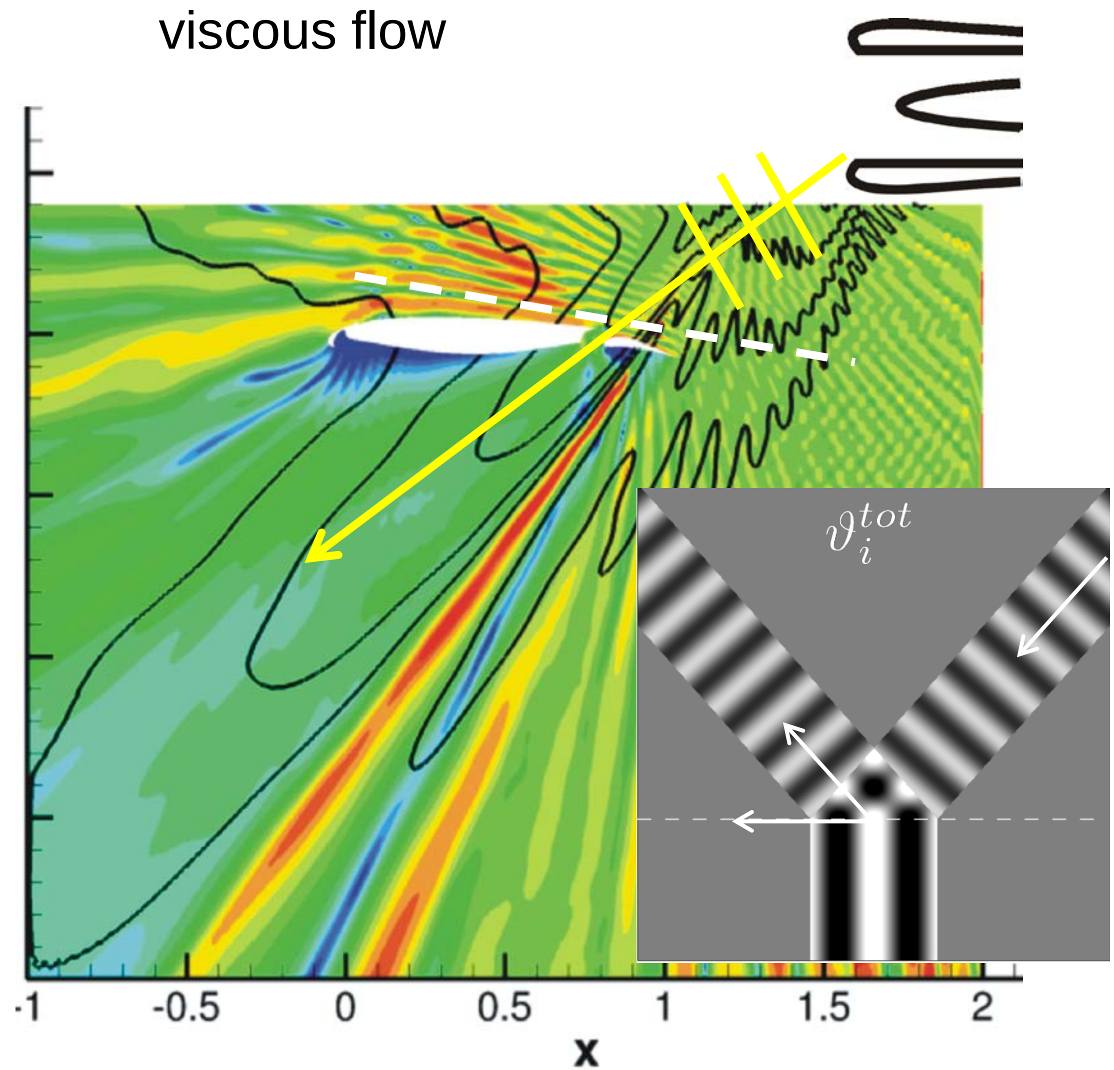
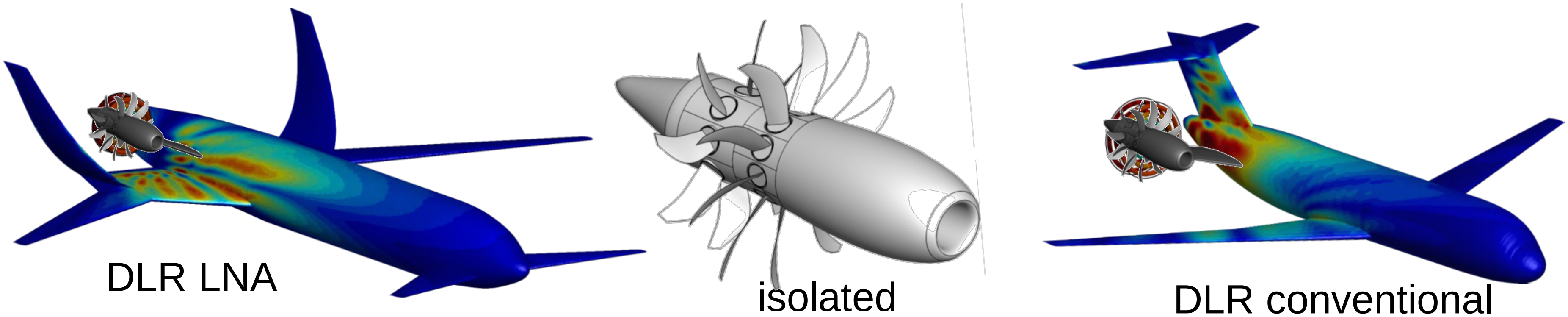
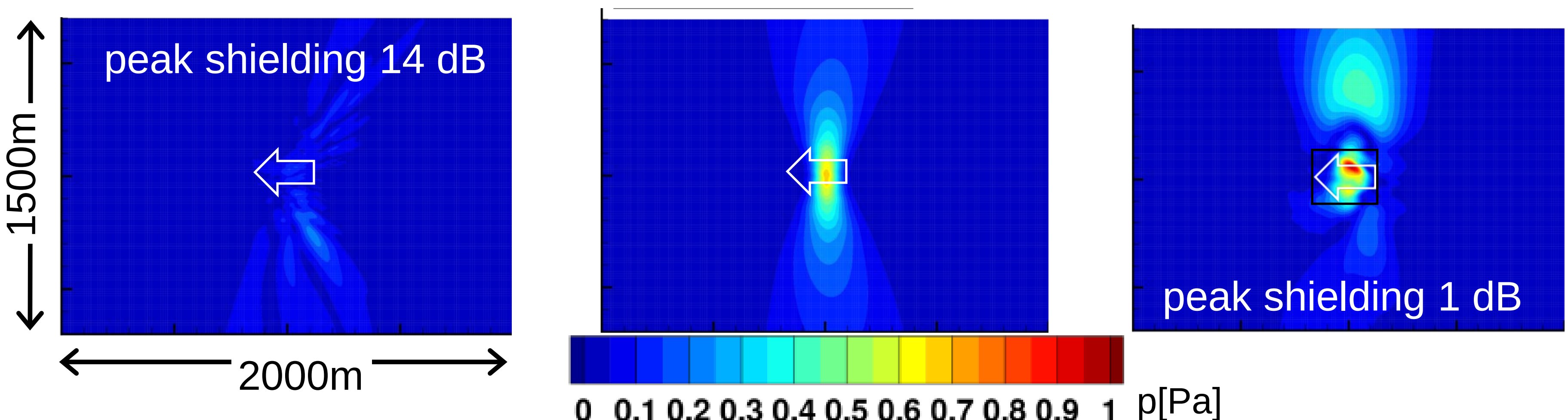




A/c configuration / shielding of CROR sound

- Ray tracing approach fails for representation of largely extended sources, e.g. Contra Rotating Open Rotors
- Need complete solution to wave equation: Fast Multipole BEM code
- Shielding of rotor alone tone $BPF_{front\ rotor}$ =171.5 Hz

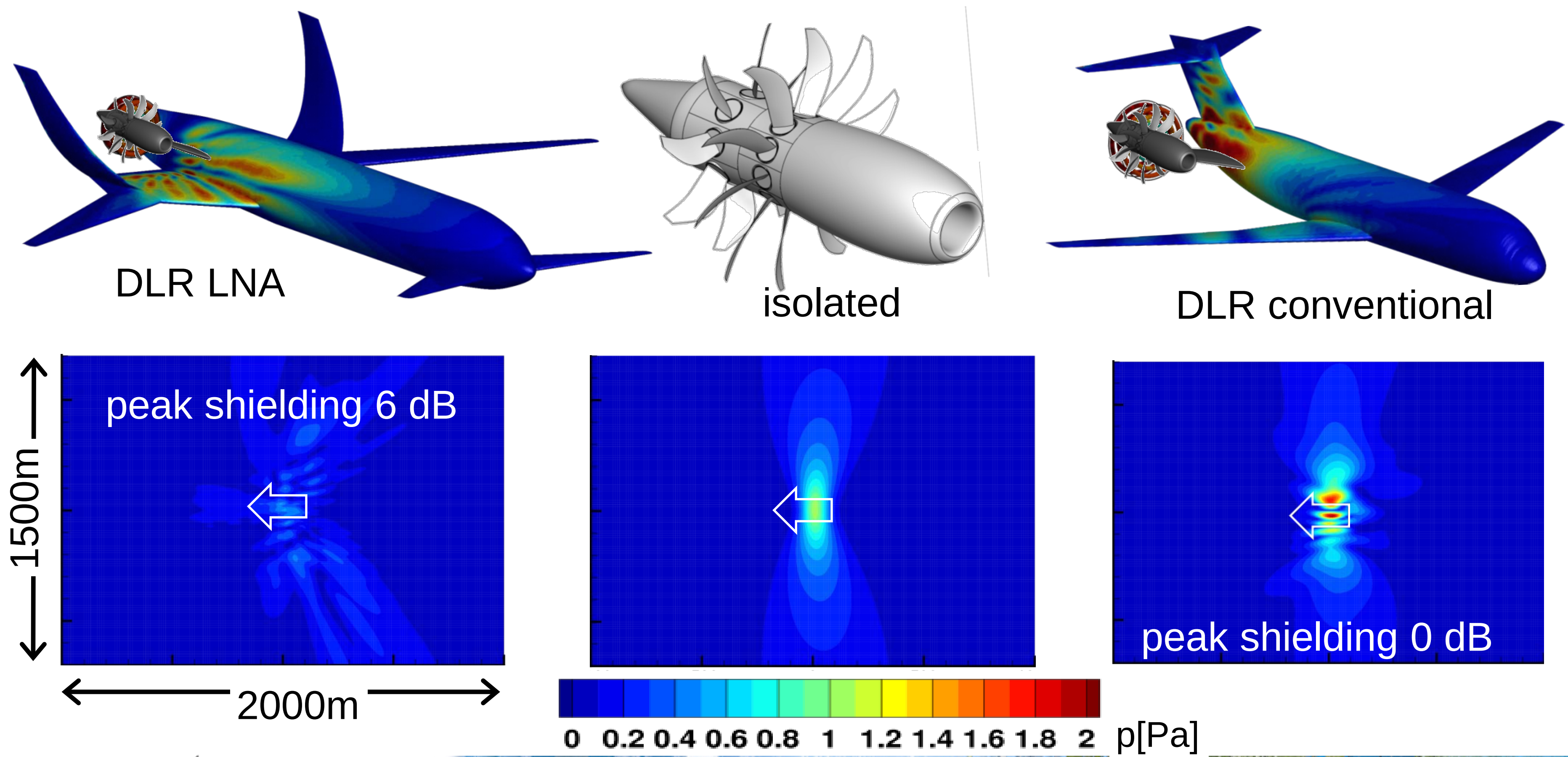




Lummer / DLR 2012

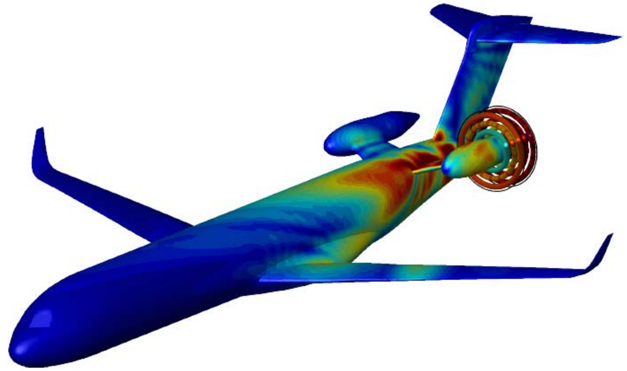
A/c configuration / shielding of CROR sound

- Shielding of rotor alone tone $BPF_{rear\ rotor}$ =137.0 Hz

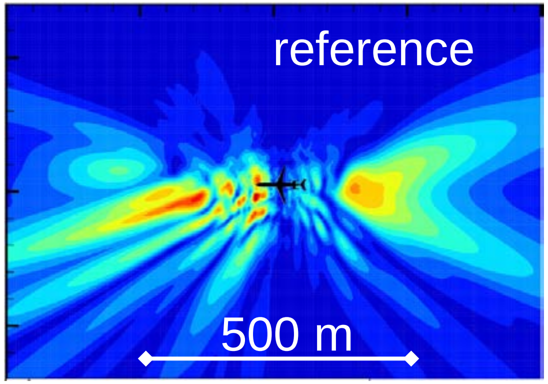


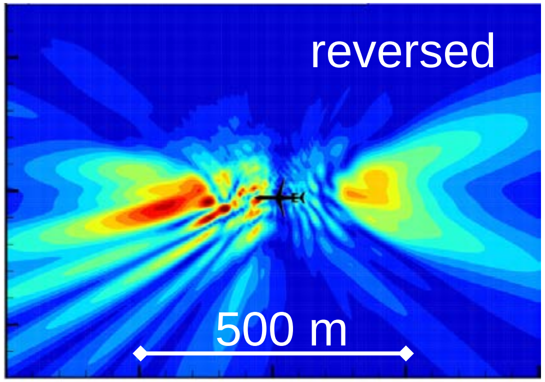
Lummer / DLR 2012

Concept and Integration

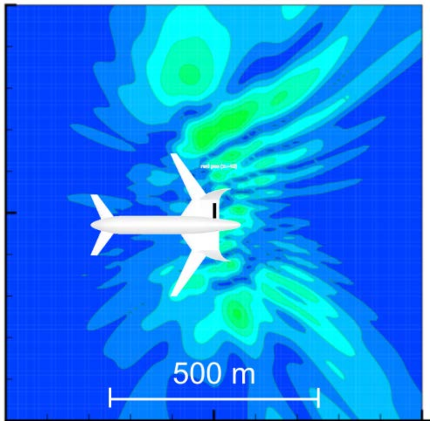


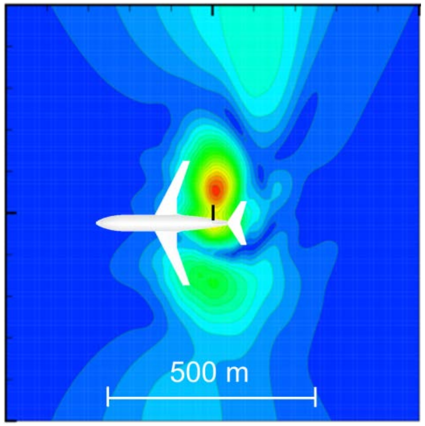
Acoustic installation effect of CROR
-sense of rotation-





Acoustic installation effect of CROR
- LNA vs. rear mounted -





Cabin noise excitation at transport aircraft

- **External noise sources:**

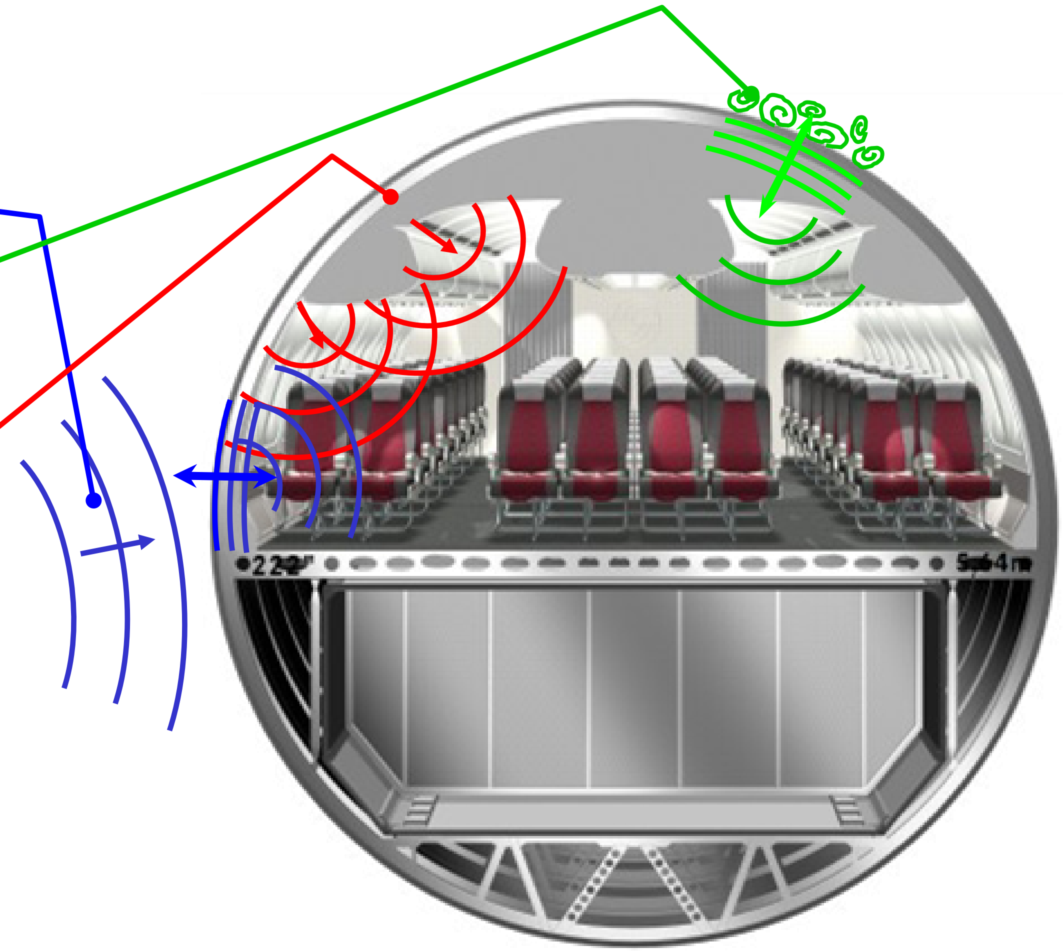
engine noise

fuselage boundary layer

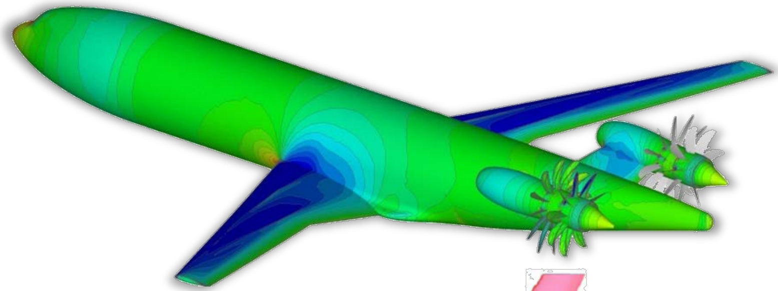
- **Interior noise sources:**

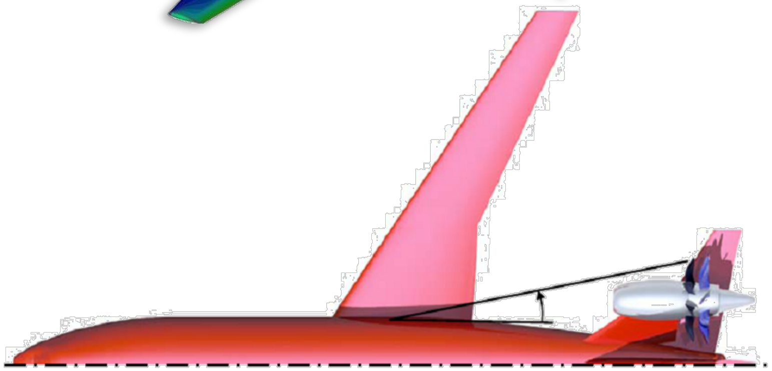
Air system

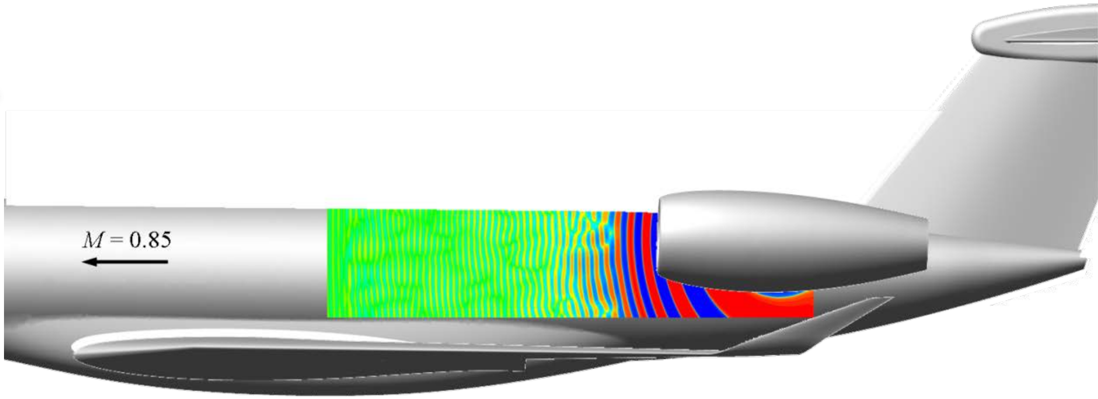
(hydraulic systems)

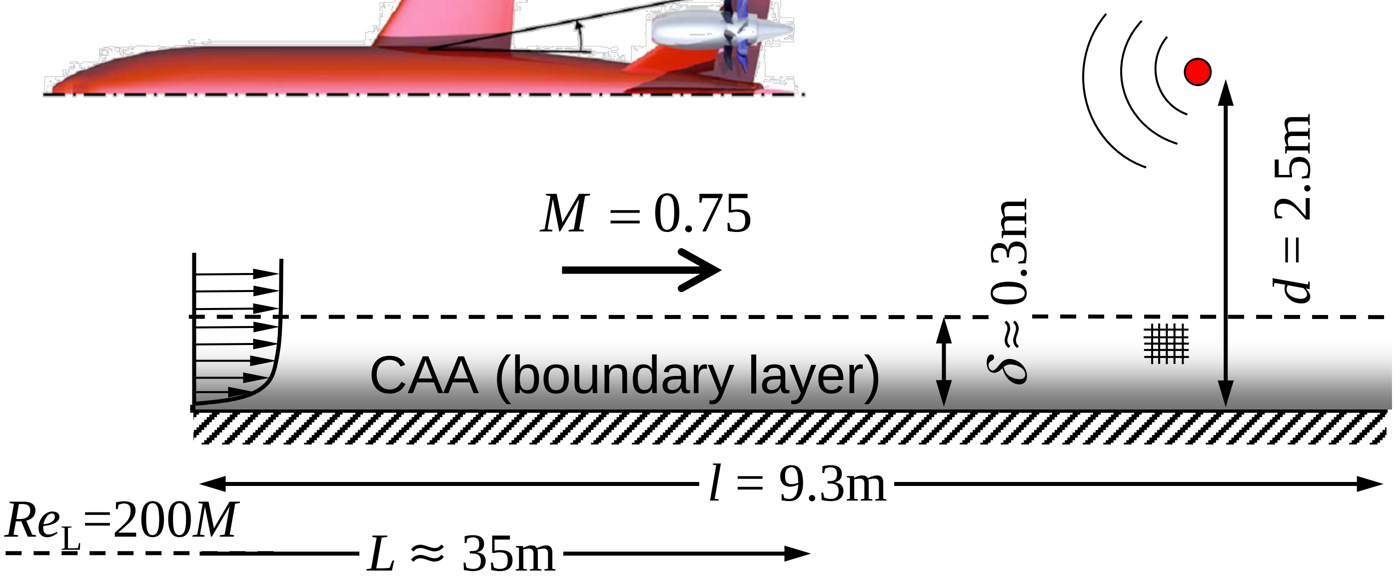


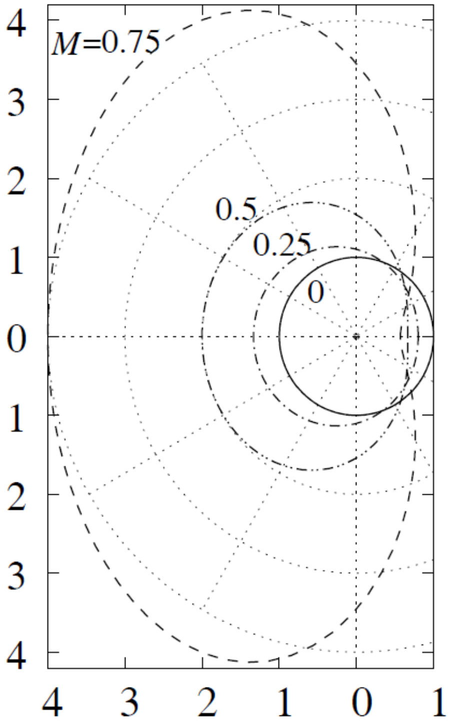
Fuselage sound pressure level from engine tone signals





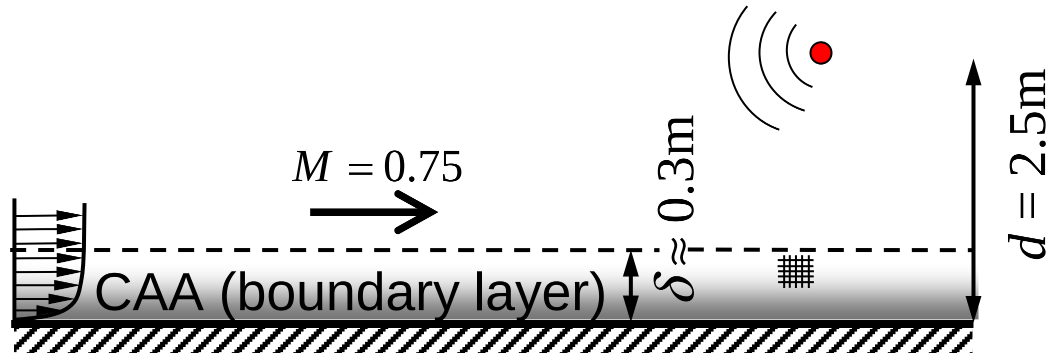




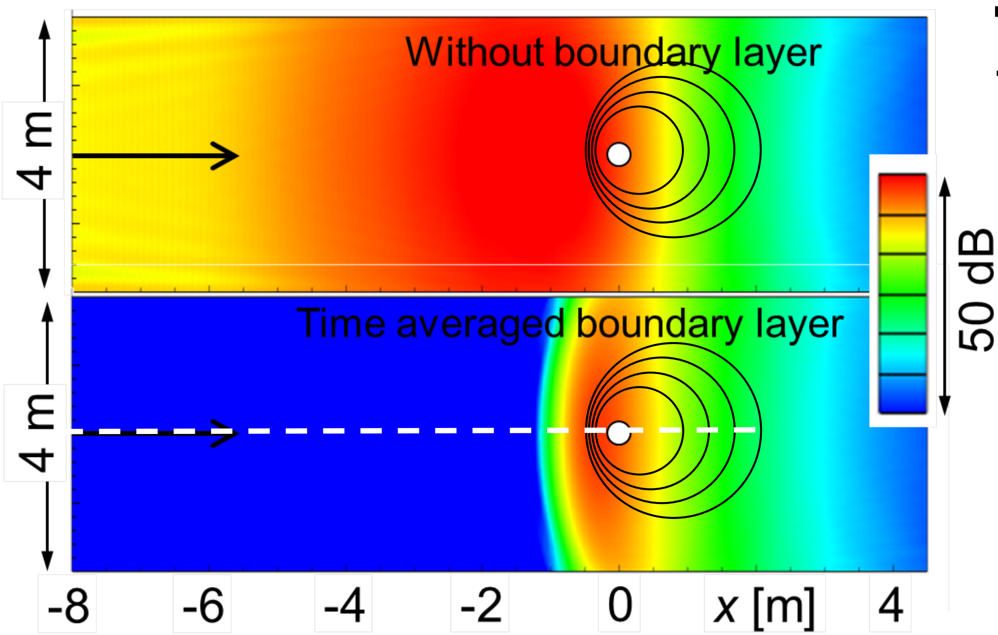


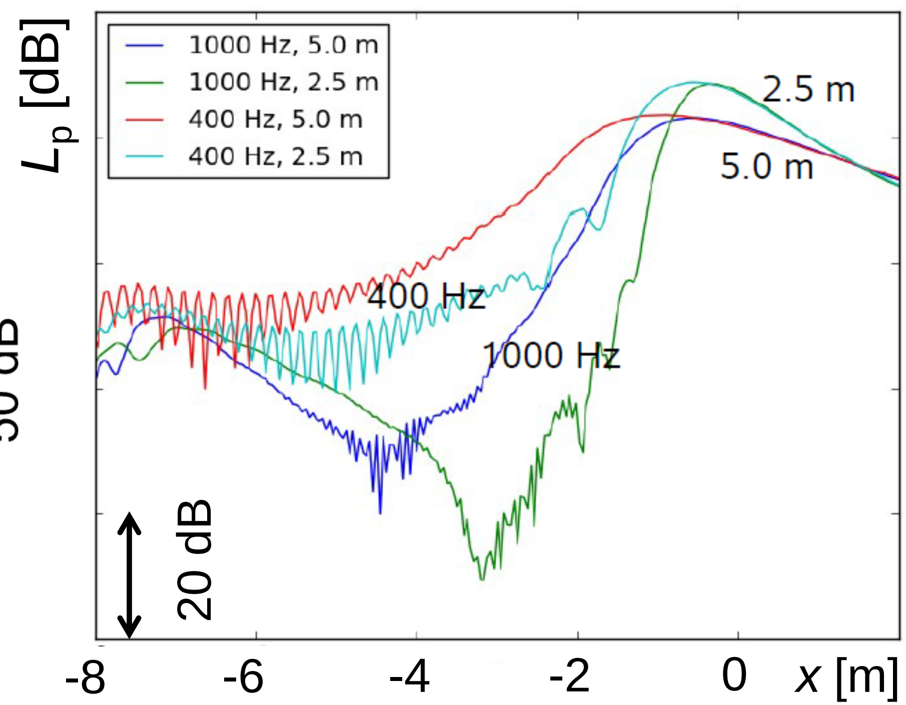
Fuselage sound pressure level from engine tone signals

- Re = 200 M
- RANS/FRPM/LEE
- active Thompson b.c. to specify incoming wave



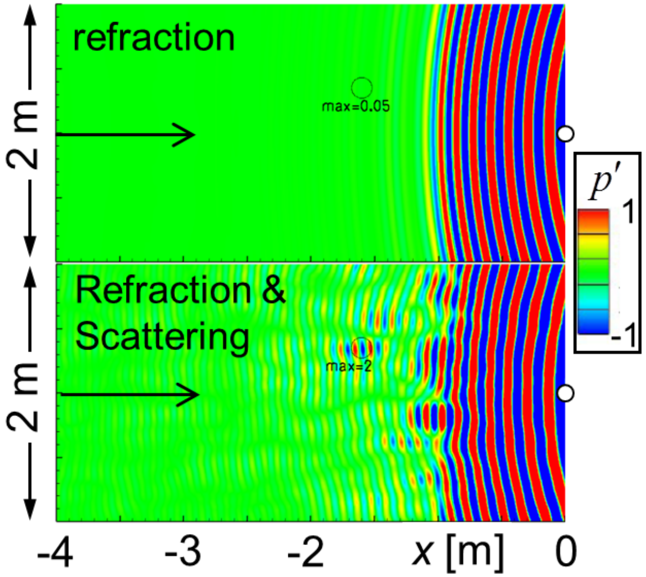
Surface pressure levels point source

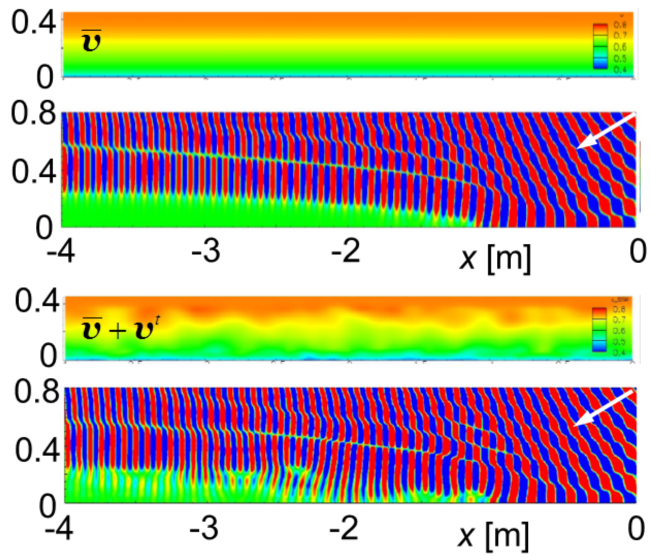


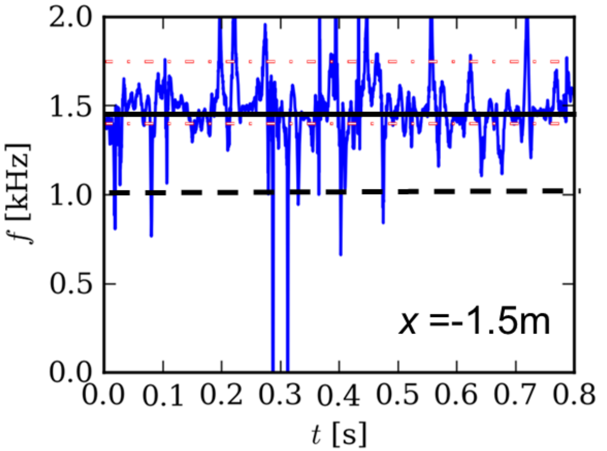


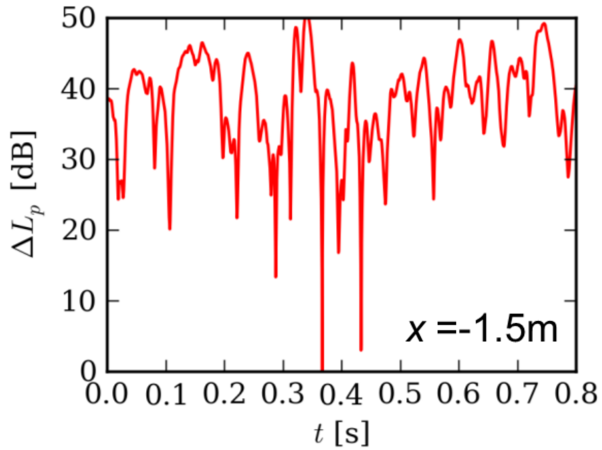
Siefert, Delfs, Caruelle, AIAA2011

Fuselage sound pressure level from engine tone signals









Refraction & Scattering at turb. eddies $\Rightarrow$ Doppler shift (position dependent) !

Siefert, Delfs, Caruelle, AIAA2011-2847

Conclusions

- significance of airframe for a/c noise is high and related to
  i) component source noise
  ii) installation sources
  iii) acoustic installation effects
- high lift system is THE challenge for approach noise
- noise of new generations of transport a/c will be dominated by installation sources
- a/c exterior/interior noise depends on the installation of the engine. Effects may be exploited at current and new a/c configurations

Outlook

- challenges in airframe component noise:
  - flow permeable trailing edges extremely efficient reduction devices
    why do they work? how can one predict/model their effect?
  - efficient non-empiric aero-acoustic design capability
  - Adaptive structures/ active flow control?
- challenges in source installation effects:
  - Definition of relevant, but generic test cases
  - Hard to do validation, necessarily in large acoustic facilities
- challenges in acoustic installation effects:
  - Full a/c simulation for frequencies up to 10kHz?
  - Taking into account viscous flow effects on shielding
  - Realistic prediction of engine related fuselage pressure fluctuations: boundary layer effects extremely important, i) hard to simulate. ii) extremely hard to measure!